JOURNAL

OF THE

AMERICAN SOCIETY OF AGRONOMY

VOLUME 23

1931

PUBLISHED BY THE SOCIETY

THE W. F. HUMPHREY PRESS
GENEVA, N. Y.

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JOURNAL

OF THE

American Society of Agronomy

VOL. 23 JANUARY, 1931 NO. 1

EFFECT OF LEAF RUST INFECTION ON YIELD OF CERTAIN VARIETIES OF WHEAT[1]

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It often has been stated by investigators as well as farmers that very little loss results from heavy infection with leaf rust of wheat, *Puccinia triticina*. Even today losses from this source usually are underestimated and frequently entirely overlooked. This tendency is partially due to the failure of most people to differentiate between the type of injury caused by stem rust and that caused by leaf rust. Stem rust is by far the more destructive and more spectacular parasite when conditions favor its development. Frequently striking late in the season, it often ruins a promising crop within a few days, leaving only light, shriveled, poorly-matured grain scarcely worth harvesting.

Leaf rust, on the other hand, frequently is present much earlier in the season than stem rust and gradually increases until the crop reaches maturity. Thus it is not spectacular, but rather insidious in its effect on the crop. Furthermore, its distribution, season after season, is much more widespread than that of stem rust. Leaf rust is found nearly every season in almost every part of the world where wheat is grown. It is true the amount of infection varies from season to season, but the average amount is much greater than that of stem rust. The latter rust may be very serious in one season and then may be practically absent for a period of several years. This is especially true in the hard red winter wheat growing area of the southern Great Plains where heavy infections of leaf rust occur almost annually.

[1]Contribution No. 299 from the Department of Botany and Plant Pathology, Kansas State Agricultural College, Manhattan, Kan., in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication August 4, 1930.

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Aside from the difference in prevalence of the two rusts, there are other reasons why the damage caused by leaf rust often is underestimated. Foremost among these is the fact that leaf rust seldom causes shriveling of the grain. Even under conditions of extremely heavy infections of leaf rust the grain usually is nearly as plump as that from rust-free fields. Man has learned to think of rust losses in terms of stem-rust damage, manifest in severe shriveling of the grain. He is therefore prone to believe that if there is no shriveling there is no loss. As early as 1894 Cobb (1),[3] writing of rust in Australia stated, "What is meant by the declaration that rust on the flag does no harm, is that as long as the rust is confined to the flag there will be *some* grain in the head. This is true; it is equally true that if there is no rust on the flag there will be very much *more* grain in the head, unless some cause that has no connection with rust prevents."

In 1927, Hayes, Aamodt, and Stevenson (2) found that susceptibility to leaf rust was an important factor in the yielding ability of certain spring wheats. More recently, Mains (3) has proved very definitely that leaf rust infection frequently results in severe losses. Experiments conducted by the writer at the Kansas Agricultural Experiment Station also have definitely shown that heavy infections of leaf rust may result in heavy losses.

The reason for the occurrence of shriveling under heavy stem rust infection and its absence in the case of an equally heavy leaf rust infection is readily explained by the characteristics of the two species of rust. Stem rust seldom causes heavy leaf infection, but attacks the leaf sheaths, culms, peduncles, glumes, and awns of susceptible varieties severely. This infection usually becomes severe about the time translocation of starch into the seed starts. The points of heaviest infection usually are the leaf sheaths and peduncles. The fungus, therefore, is in a strategic position to intercept materials being translocated from leaves to seed and to use them in its own growth. Thus, much of the food which normally goes into the formation of grain is intercepted and used by the fungus. It would be foolish to state that this is the only reason for shriveling due to stem rust infection, for there doubtless are several other important factors. It seems certain, however, that this is one of the principal reasons.

Leaf rust infection, on the other hand, is quite generally limited to the leaves and to some extent to the leaf sheaths. Infection of the culm, peduncles, glumes, and beards very seldom occurs. The writer has seen leaf rust infection on the stems of wheat only twice during the progress of leaf rust experiments extending over a period of eight

[3]Reference by number is to "Literature Cited," p. 12.

years. In both of these instances it occurred in extremely wet seasons and only in very small areas which had lodged rather early in the season. During the same period, leaf infections of 100% were frequently observed and infections of 80% were very common. Furthermore, heavy infection on the leaves occurred in nearly every field over large areas, while stem infections were seen only in small spots in occasional fields.

It is self-evident, of course, that a tremendous amount of food material is used by the fungus in the leaf tissues where it is manufactured. Certainly food used by the fungus cannot go into the formation of grain so there must be a very considerable loss in many seasons. A still further reduction in the amount of food material manufactured by rusted plants is caused by a reduction in the amount of photosynthetic tissues. In a heavy rust infection the tissues are ruptured and many cells killed and the loss of so much photosynthetic "machinery" must be reflected by some loss in yield. It is clear, however, that food material elaborated in the leaves in excess of that needed by the plant in metabolism and that consumed by the rust, is free to be translocated into the seed. Furthermore, considerable food material is produced in the green tissues of the leaf sheaths and immature stems. This may be translocated to the seed without danger of interception by leaf rust infection. Thus, the seeds formed by plants infected with leaf rust usually are plump and show little visible effect of the parasitism.

There is a distinct and often heavy loss from leaf rust in cases of heavy infection. Mains (3) has recently proved the point very definitely and also has shown the nature of the losses. He clearly shows that in case of heavy leaf rust infection, the tip and basal spikelets of the head often fail to set seed. He further shows that the average percentage of central florets setting seed is much smaller in infected than in rust-free plants. Throughout the entire spike there were more empty florets on rusted than on rust-free plants. The reduction in yield, however, was not reflected in shriveled seed. The kernels developed by rusted plants were nearly as plump, but not quite so large as those of plants free from leaf rust infection.

These results agree in nearly every respect with those obtained by the writer in experiments extending over three years. These latter results are presented to emphasize the fact that leaf rust of wheat does cause losses. Experiments were started in the greenhouse in the fall of 1924 and conducted during the succeeding three winters. Supplementary experiments were conducted in the field in 1925 and 1926. Results on losses in yield due to leaf rust infection therefore are available for three greenhouse years and two crop seasons in the field.

GREENHOUSE EXPERIMENTS

In the greenhouse a single known physiologic form of leaf rust was used, the inoculated plants being kept copiously infected, and control plants maintained practically free from infection. Two varieties of wheat were used, Fulhard CI 8257, a hard red winter variety highly resistant to the form of leaf rust employed in the experiment, and Malakof CI 4898, a semihard red winter wheat, susceptible to that form of rust. Physiologic form 9 was used throughout the experiments, the original culture having resulted from a carefully tested single-pustule transfer. The same source of inoculum was kept from season to season, being stored over summer in the refrigerator. The rust culture was tested at frequent intervals for purity, but no mixtures were detected during the course of the three years' work.

The plants were grown to maturity in 4-inch flower pots, there being a single plant per pot. One hundred pots of each variety were sown each year. Half of the plants of each variety were inoculated and the remainder kept as nearly rust free as possible. Thus there were 50 plants in each group at the beginning of the experiment each year, but a few plants were usually lost from each group. In no case, however, were there fewer than 46 plants in a group at the end of the season.

Inoculations were made by placing the plants in a large galvanized iron moist chamber, atomizing the leaves with tap water, and dusting heavily with spores of physiologic form 9. The plants were left in the moist chamber 48 hours then removed and placed on the greenhouse bench. All non-inoculated plants were placed in the moist chamber for the same length of time to serve as a control on the effects of the unusual environmental conditions in the moist chamber.

In 1925, and again in 1926, inoculations were made at three stages of growth, *viz.*, during the seedling, jointing, and heading stages. In 1927, the jointing stage inoculation was omitted, but heavy inoculations were made during the seedling and heading stages. Throughout the entire course of the experiments rust readings were made 14 to 16 days after inoculation. The amount of infection resulting from each inoculation was always very heavy on Malakof, averaging about 65% for the 50 plants inoculated. Some of the infection resulting from the two earlier inoculations persisted from one time to the next, but infection was always very heavy for three to four weeks after inoculation and then gradually diminished in amount. The infection resulting from the heading stage inoculation persisted until the plants matured. Thus the inoculated plants were subjected to three periods of very heavy infection separated by two

periods of diminishing infection in which the plants put out some new uninfected leaf tissue.

The inoculations of the resistant Fulhard usually resulted only in "flecking." These small light green areas in the leaf tissues were caused by the fungus killing a few of the host cells. The fungus was unable to grow in the tissues of the resistant plants, however, and soon died out without sporulation. Occasionally, a few small to minute uredinia developed on the lowermost leaves of Fulhard, but in no case was the average infection on the 50 inoculated plants of Fulhard more than 5%. In the shooting and heading stages these plants usually had flecks only. The uninoculated plants of both varieties usually showed no leaf rust infection. A few scattered uredinia, caused by natural infection, appeared on a few of the plants in the control group of Malakof, but never enough to cause a measurable effect in the results. Most of these plants usually were entirely free from rust.

At maturity the heads on each plant were counted and harvested. The grain from each plant was then threshed separately and stored in paper envelopes. After drying for several weeks the number of kernels and grain weight of each sample were determined and recorded. All weighing was done on scales sensitive to 0.01 gram. All weights given in Table 1 are calculated from the total weights and do not represent separate weighings.

The results secured in the three years' greenhouse experiments are summarized in Table 1. It is seen immediately that there is a large loss in yield in the inoculated plants of the rust-susceptible Malakof. The total number of plants was nearly the same for both the inoculated and non-inoculated groups, but the latter group produced nearly twice as many kernels and more than twice as much grain in weight. There was a slight reduction in the total number of plants in the inoculated group, and a reduction of 9.11% in the average number of heads per plant. Further analysis shows a reduction of 40% in the average number of kernels per plant and of 39.89% in the average number of kernels per head. The percentage of reduction in the average weight of grain per plant was 47.34 and in average weight of grain per head 47.50. These percentages are 7.34 and 7.61 larger than the corresponding reductions in number of kernels. This would seem to indicate that there is some reduction in yield other than that explained by the reduction in the number of kernels. The explanation probably lies in the slightly smaller size of the grains from inoculated plants. The figures show a loss of 13.33% in weight of the individual kernels from rusted plants. This figure may be a little too high as it

TABLE 1.—*Effect of leaf rust on yield of wheat in the greenhouse, Manhattan, Kan., 1925–1927.*

Variety and treatment	Year	Total number of			Average number of			Total weight of grain in grams	Average weight in grams of grain per		
		Plants	Heads	Kernels	Heads per plant	Kernels per plant	Kernels per head		Plant	Head	Kernel
Malakof, C. I. 4898											
Not inoculated	1925	47	174	3,113	3.70	66.20	17.80	101.51	2.16	0.58	0.033
	1926	49	354	5,647	7.22	115.24	15.95	166.11	3.39	0.47	0.029
	1927	46	498	2,708	10.80	60.18	5.43	80.44	1.79	0.16	0.029
Average, 3 years		47.33	342	3,822.6	7.24	80.54	13.06	116.02	2.45	0.40	0.030
Inoculated	1925	47	170	1,033	3.6	21.90	6.00	22.28	0.47	0.13	0.022
	1926	48	302	4,463	6.3	92.90	14.70	123.18	2.57	0.41	0.028
	1927	46	488	1,387	10.6	30.15	2.84	38.68	0.84	0.08	0.027
Average, 3 years		47	320	2,284.3	6.8	48.32	7.85	51.38	1.29	0.21	0.026
Difference		0.33	22	1,538.3	0.66	32.22	5.21	64.64	1.16	0.19	0.004
Per cent reduction		0.69	6.43	40.24	9.11	40.00	39.89	55.71	47.34	47.50	13.33
Fulhard, C. I. 8257											
Not inoculated	1925	47	188	3,464	4.0	73.70	18.40	100.36	2.13	0.53	0.029
	1926	48	308	4,799	6.4	85.39	13.30	121.01	2.52	0.39	0.030
	1927	50	376	4,279	7.5	85.58	11.38	135.16	2.70	0.36	0.031
Average, 3 years		48.3	290.6	3,947.3	6.0	81.56	14.36	118.84	2.45	0.43	0.030
Inoculated	1925	47	179	1,665	3.80	35.40	9.30	39.59	0.84	0.22	0.024
	1926	47	271	4,041	5.77	85.98	14.91	131.49	2.80	0.49	0.033
	1927	50	434	3,362	8.70	66.24	7.74	105.90	2.12	0.24	0.031
Average, 3 years		48	294.6	3,022.6	6.09	62.54	10.65	92.33	1.92	0.32	0.029
Difference		0.3	+4.0	924.7	+0.09	19.02	3.71	26.51	0.53	0.11	0.001
Per cent reduction		0.62	+1.37	23.42	+1.50	23.32	25.83	22.30	21.63	25.58	3.33

was necessary to figure weights to three decimal places, but they undoubtedly show a definite reduction. There can be little doubt, therefore, that the kernels from the inoculated plants were somewhat smaller than those from non-inoculated plants. Frequently this was easily seen, but at other times was not so obvious. In many cases the grain from inoculated plants contained a rather large number of small kernels. These were perfectly formed and plump, but were much smaller than kernels of that variety normally should be.

The data secured on the rust-susceptible Malakof would indicate that leaf rust caused an average loss in yield of 55.71% in total weight of grain for a three-year period. This loss seems to have been due principally to a decrease in the average number of kernels per head. Part of the loss apparently was caused by slight reduction in the average number of heads per plant and by a reduction in the size of the individual kernels.

The losses caused by leaf rust infection in a susceptible variety like Malakof are not surprising, but the reductions in yield noted for the resistant Fulhard are somewhat so. As shown in Table 1, the inoculated group averaged 22.05% less in total weight of grain than the uninoculated. This was a much greater loss than expected and is probably greater than usually occurs in the field. Fulhard is highly resistant to leaf rust physiologic form 9, only a few minute uredinia being formed on the lower leaves. Flecking, on the other hand, is very copious, the leaves frequently being somewhat chlorotic due to severe flecking caused by leaf rust infection. It was to get a measure of the effect of this condition on yield that Fulhard was included in these experiments. Under the conditions of the experiments flecking apparently exerted a very marked effect on yield. It is only reasonable to expect that some reduction would result from abundant flecking, for, in such cases, many leaf cells are killed. The number of cells available for the elaboration of food materials, therefore, is greatly reduced. It must be kept in mind, however, that conditions as severe as those under which these experiments were conducted seldom prevail in the field. This would be especially true if a resistant variety were grown extensively. Such a practice would diminish the amount of inoculum to a negligible quantity and therefore there would be practically no necrosis.

It will be noted in the case of Fulhard that there was a slight increase instead of a decrease in the average number of heads per plant in the inoculated group. It is also interesting to note that the average weight of the individual kernels is only 3.33% less in the inoculated group. A difference so small is of little or no significance.

That there is very little reduction in the size of the kernels in this variety is also indicated by the close agreement of the percentage of reduction in the average number of kernels per plant and average weight of grain per plant, and likewise in the average number of kernels per head and the average weight of grain per head. The differences in this case were only 1.69 and 0.26%, respectively. Apparently, then, the principal source of reduction in yield in this case is in the smaller number of kernels produced.

Although a loss of 22.30% due to leaf rust infection seems rather high for a resistant variety, it probably is not unreasonable when the conditions of the experiment are considered. In 1925 and 1926 the plants were inoculated three times and in 1927 twice during their life history. Each time heavy infection occurred, although this was shown only by heavy flecking in the resistant Fulhard. In this variety, however, the flecks on the leaves were as numerous as the rust sori on the susceptible Malakof. Since flecks are caused by the killing of small areas of leaf cells by the fungus, a considerable number of cells must have been killed in each leaf at each inoculation. It seems entirely within reason that a considerable reduction in the number of living cells would be reflected in the yield of grain. The reduction in yield of the susceptible Malakof was 55.71% in total weight of grain. This is 33.41% greater than that noted for Fulhard. It seems likely, therefore, that the loss in yield in a resistant variety, even under the most severe conditions, is only about one-third of that caused by leaf rust infection in a susceptible variety.

The results of the experiment with Fulhard are somewhat less convincing than those with Malakof, and therefore should be repeated. The fact that in 1926 the inoculated plants of Fulhard yielded a little more than the non-inoculated plants and the further fact of the wide difference in the yield of the two groups secured in 1925, clearly indicates the necessity of further experiments. In the opinion of the writer, the fact of heavy losses from leaf rust infection on a susceptible variety is clearly demonstrated. The nature of these losses also is indicated with considerable clarity. That these results agree with those obtained by Mains (3) in more extensive experiments undoubtedly is not accidental. There can be little doubt that inoculations of resistant varieties sufficiently heavy to cause chlorosis may result in some loss in yield. Whether this loss is as large as that indicated by these experiments should be determined.

FIELD EXPERIMENTS

The field experiments on the effect of leaf rust on yield of wheat were not so extensive as the greenhouse experiments. The results obtained are presented here to supplement the greenhouse results and to lend further emphasis to the fact that definite losses result from leaf rust infection. Field experimentation is obviously attended by the impossibility of controlling the amount and kind of diseases appearing in non-treated plats. The experimenter must depend largely on natural infection. Even though a known physiologic form of leaf rust be placed in the plats as inoculum and the best possible conditions for infection be made, the final amount of infection is greatly dependent on seasonal conditions. Furthermore, there is no practical way to exclude such other wind-borne diseases as stem rust, mildew, leaf blotch, and glume blotch. Another factor that complicates this sort of field experiment lies in the necessity of using some chemical treatment or special protective device to keep the control plats as nearly disease-free as possible. Thus field experiments of this nature would seem to be open to a greater number and variety of errors than greenhouse experiments. The final proof of losses, however, must come from field experiments, for if losses do not occur under field conditions, the disease may be considered of no economic importance.

Studies on losses caused by leaf rust of wheat in the field were conducted at Manhattan, Kansas, in 1925 and 1926. In these experiments the control plats were kept as free as possible from rust infection by dusting with superfine sulfur every second day during the period of heavy leaf rust infection in the field. In 1925, 12 8-foot rows of Prelude spring wheat were sown on March 27. Beginning on May 15, six rows were dusted every second day with Niagara Sulfodust except when rain prevented, in which case the dust was applied as soon as the leaves had dried. Only enough sulfur was applied at a time to give the leaves a dusty appearance. Drifting of the chemical from the treated to the non-treated plats was prevented by placing a large beaver-board screen between the plats during the dusting operation. The difference in the amount of leaf rust infection in the treated and non-treated plats was very noticeable by June 15. At harvest time the non-dusted plat was very heavily infected, while the dusted plat exhibited very little rust except around the edges, where it was difficult to keep the leaves covered with dust.

When the crop was mature, each row was harvested separately and several 1-gram samples were removed at random from each lot of grain for counts on the number of kernels per gram. The average

yield per acre of the treated and non-treated plats was then calculated and the difference taken as the loss caused by leaf rust.

For the 1926 experiment, 24 8-foot rows of Turkey winter wheat were sown in the fall of 1925. An infection of leaf rust was started in these rows early in the spring and the sulfur dusting of 12 rows was begun soon thereafter. The method and frequency of dusting and methods of harvesting and handling the seed were the same as those employed in 1925. Considerable stem rust developed in the non-dusted plats in 1926, but most of the heavy infection consisted of leaf rust. One row in the dusted plat was injured by chinch bugs and was, therefore, discarded from the experiment. The corresponding row in the non-treated plat also was discarded in order that there might be the same number of rows in each plat.

The data secured in these two years' experiments are summarized in Table 2. It will be noted that the dusted plats yielded 1.7 and 2.3 bushels more, respectively, than the non-dusted plats. Most of this difference probably was due to the greater freedom of the dusted plats from leaf rust, as all other factors were kept as nearly identical as possible. If this is assumed to be the case, we have a reduction in yield of 8.1% in 1925 and 7.7% in 1926. These are much smaller decreases than those noted in the greenhouse. The reason for the difference lies principally in the difference in the length of time the host and parasite were associated in the two locations. In the greenhouse, the rusted plants were constantly infected from the seedling stage to maturity. In the field the plants were relatively free from leaf rust infection until about heading time. There seems, however, to be a very definite loss in yield in the field and one well worth considering, if these experiments are significant.

TABLE 2.—*Comparison of the yield of Prelude and Turkey wheat in field plats dusted with sulfur for the control of rust with similar non-dusted plats, Manhattan, Kansas, 1925 and 1926.*

Year	Variety	Treatment	No. of rows	Total weight of seed in grams	Ave. yield in bushels per acre	Ave. No. of kernels per gram of seed	Ave. percentage of rust
1925	Prelude	Dusted	6	628	20.9	46.5	26
1925	Prelude	Non-dusted	6	577	19.2	47.8	72
		Difference	0	—51	—1.7	+1.3	+46
1926	Turkey	Dusted	11	1,631.09	29.6	47.3	20
1926	Turkey	Non-dusted	11	1,503.38	27.3	57.5	65
		Difference	0	—127.71	—2.3	+10.2	+45

It is interesting to note that one of the effects of leaf rust in the field was a decrease in the size of kernels from infected plants. This is brought out in Table 2 in the average number of kernels per gram of seed. There was a greater number of kernels per gram in seed from the non-dusted (heavily rusted) rows in both years. In 1925, the difference between dusted and non-dusted rows in this respect was much smaller than in 1926. This probably was due to the difference in the two varieties of wheat. In 1925, it was noted that the heads of Prelude in the non-dusted plat were smaller but seemingly as well filled as those in the dusted plat. The 1926 results probably were somewhat affected by the stem-rust infection in the non-dusted plot of Turkey, for some shrunken kernels appeared in the seed from that plat. This was reflected in the plumpness readings made on the grain from the dusted and non-dusted rows. The dusted rows gave an average of 91.6% plump grains, while seed from non-dusted rows averaged only 75% plump. Thus, it seems that at least part of the decrease in size of kernels in the non-dusted plat in 1926 was due to shriveling. In general, however, the field and greenhouse results agree in that one of the reasons for diminished yield due to leaf rust lies in the smaller size of individual kernels from rusted plants. While the field experiments were not conducted on a scale large enough to justify the drawing of definite conclusions, they seem to substantiate the results secured in the greenhouse and to indicate that definite losses result from heavy leaf-rust infection in the field.

SUMMARY

Experiments conducted for three years in the greenhouse and for two years in the field at Manhattan, Kansas, proved that heavy infections of leaf rust greatly reduced the yield of wheat.

In the greenhouse, the yield of Malakof CI 4898, a susceptible variety, was reduced 55.71%, while a reduction of 22.30% was noted for Fulhard CI 8257, a resistant variety.

In the susceptible variety, the loss in yield was due principally to a reduction in the number of kernels produced, although there also was a slight reduction in the number of heads per plant and in the size of the individual kernels.

The loss in yield in a resistant variety, such as Fulhard, probably is due to the killing of many of the green leaf cells. This is visibly expressed in the form of flecking. In these experiments the loss in yield in the resistant variety was about one-third of that in the susceptible variety.

No shriveling of the grain resulted from heavy leaf rust infection in the greenhouse. The seed from inoculated plants frequently contained many small kernels. These, however, were plump and well formed.

Experiments conducted in the field with Prelude spring wheat and Turkey winter wheat substantiated the results of the greenhouse experiments.

Partial control of rust in field plats by sulfur dusting at two-day intervals during the late spring resulted in an increase of 1.7 bushels per acre for Prelude and 2.3 bushels per acre for Turkey.

Field experiments also indicated that at least part of the reduction in yield due to leaf rust was caused by the smaller size of individual kernels of the infected plants.

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INFLUENCE OF POTASH SOURCES AND CHLORINE CONTENT OF FERTILIZERS ON YIELD OF COTTON[1]

J. J. SKINNER[2]

The experiments reported in this paper were planned to compare muriate of potash, sulfate of potash, and kainit as sources of potash for cotton in fertilizers mixed with superphosphate and nitrogen materials. These experiments are a part of general fertilizer investigations pertaining to cotton problems in the southeastern states. The suitability of potash materials containing chlorine, especially when used in large amounts and on sandy soils of the southeastern Coastal Plains, is of considerable interest and many inquiries concerning their effect on yield and quality of the agricultural products grown there have been received.

The effect of chlorides, applied to the soil, on crop yields has been the subject of experimentation for many years and investigations have been made with pots and water cultures. The results generally agree that if chlorine is necessary for normal plant growth, the quantity required must be small. It is generally shown that plants differ in their response to this element and vary in tolerance to increasing quantities. The literature on the effect of chlorine on plant growth has been reviewed by Tottingham (5)[3] and Lomanitz (1) and more recently by Garner, *et al.* (2), and its further development is not deemed essential in connection with this paper.

No evidence has been secured in these investigations to show that chlorine from potassium chloride in amounts ordinarily used in mixed fertilizer affects the yield or quality of cotton adversely. It has been observed, however, when muriate of potash is used in complete fertilizers, the nitrogen of which is derived from ammonium chloride, that the growth of cotton plants is frequently checked and yields reduced, but this has not been the case in all of the experiments reported.

The data presented below show in a general way that potassium chloride gives as good results with cotton as other salts of potash, but indicate that it is possible to acquire an excess of chlorine in fertilizers under some conditions.

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Received for publication August 15, 1930.

[2]Senior Biochemist.

[3]Reference by number is to "Literature Cited," p. 21.

TABLE 1.—*Effect of various sources of potash in mixed fertilizer on yield of cotton on 12 Coastal Plain soils.*

Soil type	Location	Year	Fertilizer analyses* (NH_3-P_2O_5-K_2O)	Pounds of fertilizer per acre	Pounds of seed cotton per acre: Muriate of potash	Pounds of seed cotton per acre: Sulfate of potash	Pounds of seed cotton per acre: Kainit
Norfolk sandy loam	Darlington, S. C.	1921	5-7-4	900	1,720	1,810	1,325
Norfolk sandy loam	Darlington, S. C.	1922	5-7-4	900	780	900	750
Norfolk fine sandy loam	Florence, S. C.	1920	4-8-4	900	1,580	1,520	1,280
Norfolk sandy loam	Hartsville, S. C.	1923	5-7-4	900	1,240	1,200	1,020
Norfolk sandy loam	Hartsville, S. C.	1924	5-7-4	900	1,080	980	1,100
Marlboro fine sandy loam	Bennettsville, S. C.	1921	5-7-4	900	1,520	1,560	1,540
Marlboro fine sandy loam	Bennettsville, S. C.	1922	5-7-4	900	980	1,050	1,020
Marlboro fine sandy loam	Bennettsville, S. C.	1923	5-7-4	900	1,320	1,260	1,280
Marlboro fine sandy loam	Seaboard, N. C.	1925	6-8-4	900	1,426	1,357	1,311
Marlboro sandy loam	Wilson, N. C.	1926	6-8-4	900	1,247	1,349	1,138
Marlboro sandy loam	Wilson, N. C.	1927	6-8-4	900	1,493	1,639	1,479
Portsmouth sandy loam	New Bern, N. C.	1921	5-7-4	900	1,174	1,230	1,090
Portsmouth sandy loam	New Bern, N. C.	1922	5-7-4	900	360	400	358
Ruston sandy loam	Fayetteville, N. C.	1921	5-7-4	900	1,619	1,450	1,610
Ruston sandy loam	Fayetteville, N. C.	1922	5-7-4	900	1,331	1,298	1,199
Wickham fine sandy loam	Fayetteville, N. C.	1923	5-7-4	900	954	1,026	774
Wickham fine sandy loam	Fayetteville, N. C.	1924	5-7-4	900	810	738	640
Greenville sandy loam	Weldon, N. C.	1926	6-8-4	900	1,980	2,040	1,940
Greenville sandy loam	Weldon, N. C.	1927	6-8-4	900	1,780	2,140	1,580
Dunbar fine sandy loam	New Bern, N. C.	1920	5-7-4	900	810	610	710
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1921	6-8-4	900	1,020	1,060	1,100
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1922	6-8-4	900	320	440	320
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1923	6-8-4	900	1,050	1,050	1,155
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1924	6-8-4	900	850	820	900
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1925	6-8-4	900	1,560	1,650	1,274
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1926	6-8-4	900	1,680	1,700	1,590
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1927	6-8-4	900	1,556	1,608	1,586
Norfolk very fine sandy loam	Pee Dee Exp. Sta., Florence, S. C.	1928	6-8-4	900	664	592	648
Average					1,212	1,231	1,133

*The nitrogen in the fertilizer is stated in percentages of ammonia, which was common practice when these experiments were in operation. Sources fertilizer materials: Phosphoric acid from superphosphate; potash, as noted; nitrogen, one-third each from sodium nitrate, sulfate of ammonia, and cottonseed meal.

TABLE 2.—*Effect of various sources of potash in mixed fertilizers on yield of cotton on five Piedmont soils.*

Soil type	Location	Year	Fertilizer analysis* (NH_3-P_2O_5-K_2O)	Pounds of fertilizer per acre	Pounds of seed cotton per acre		
					Muriate of potash	Sulfate of potash	Kainit
Cecil clay loam	Athens, Ga.	1921	4-10-4	600	1,134	1,106	1,126
Cecil clay loam	Athens, Ga.	1922	4-10-4	600	690	760	670
Cecil clay loam	Athens, Ga.	1923	4-10-4	600	800	720	760
Cecil clay loam	Athens, Ga.	1924	4-10-4	600	660	660	770
Cecil clay loam	Athens, Ga.	1926	4-10-4	600	500	625	450
Cecil clay	Shelby, N. C.	1925	6-10-4	900	812	754	754
Davidson Clay	Linwood, N. C.	1926	5- 7-4	900	1,300	1,270	1,070
Davidson Clay	Linwood, N. C.	1927	5- 7-4	900	1,450	1,550	1,400
Georgeville silt loam	Ashboro, N. C.	1921	5-10-4	600	990	795	975
Appling sandy loam	Kings Mt., N. C.	1925	6- 8-4	900	1,053	1,131	949
Average					938	937	892

*Sources of fertilizer ingredients: Phosphoric acid from superphosphate; nitrogen, one-third each from sodium nitrate, ammonium sulfate, and cottonseed meal; potash as noted.

EXPERIMENTAL RESULTS WITH POTASH SOURCES

In Table 1 are given the results of experiments made in North Carolina and in South Carolina on 12 soil types, using potassium sulfate, potassium chloride, and kainit as sources of potash in fertilizers mixed with superphosphate and nitrogen materials. The nitrogen in the fertilizers was derived one-third each from sodium nitrate, sulfate of ammonia, and cottonseed meal. Seven of these experiments were repeated on the same plats two years, one for 3 years and one for 8 years. In all, 28 tests were made on Coastal Plain soils.

In only a few experiments did the yields vary widely. In 15 cases sulfate of potash gave the largest yields, in 9 muriate gave largest yields, and in only 4 did kainit give the largest yields. An average of all the experiments on the Coastal Plain soils gave a slightly higher yield for the sulfate which exceeded the muriate by 19 pounds per acre and was within the range of experimental error. The average of the yields from kainit was 98 pounds per acre below the average yield from the sulfate of potash.

The results of experiments with three potash materials on five Piedmont soils in Georgia and North Carolina are given in Table 2. One of these experiments was made for 5 years on the same plats, one was for 2 years, and three were for 1 year. The yields from the three materials again do not vary widely. In all, 10 tests were made on Piedmont soils. In five of these the muriate of potash gave the largest yield, in four the sulfate gave the largest yield, and in only one did kainit give the largest yield. The average yield of all the experiments is practically the same for the muriate as for the sulfate and slightly lower for kainit. From the data, there could be no claim that the muriate or sulfate salt was superior on the Piedmont soils, nor does the data show that kainit is markedly inferior.

The yields were slightly lower with kainit, especially on the light Coastal Plain soils. When the potash was derived from potassium chloride, there was no indication of unfavorable reaction from the chlorine carried in the fertilizers from those mixtures containing 4% potash, applied at the rate of 600, 900, and 1,200 pounds per acre. In these mixtures a comparatively small amount of chlorine was contained in the fertilizers. The muriate of potash used contained 50% potash (K_2O) and 47.0% chlorine. The kainit contained 14% potash (K_2O) and 46.0% chlorine. Where 900 pounds per acre of the 4% potash mixture was used, 29 pounds per acre of chlorine was supplied from potassium chloride and 118 pounds from kainit. The amount supplied by potassium chloride had no detrimental effect. The smaller

yields from the fertilizer containing kainit may possibly be attributed to its high chlorine content. Subsequent experiments, made in connection with a study of nitrogen materials, throw further light on the influence of the chlorine content of fertilizer on the growth and development of the cotton plant.

EXPERIMENTAL RESULTS WITH POTASH AND NITROGEN SALTS CONTAINING CHLORINE

The results given in Tables 3 and 4 were secured in a study of the effects of ammonium chloride used as the source of nitrogen in fertilizers with superphosphate and potassium sulfate in one case and superphosphate and potassium chloride in another (3, 4). Ammonium nitrate was used as a source of nitrogen with potassium sulfate, and these results are given, which are for a fertilizer containing no appreciable chlorine. Although the source of potash or the source of nitrogen varies in the three fertilizers, the data show the results secured with fertilizers containing no chlorine and varying amounts of chlorine, of interest in connection with the problem of the chlorine content of cotton fertilizer.

The experiments were made on nine soil types in the Coastal Plain and three types in the Piedmont region. Four were made for 2 years on the same plats and one for 3 years.

A considerable amount of chlorine supplied in the ammonium chloride is contained in the fertilizers of groups I and II of Tables 3 and 4. Where 900 pounds of 6–8–4[4] fertilizer were used, 112 pounds per acre of chlorine were supplied from ammonium chloride and 29 pounds from potassium chloride, making a total of 141 pounds in the muriate of potash mixtures and 112 pounds in the sulfate of potash mixtures. This difference of 29 pounds per acre was sufficient to affect the crop unfavorably in the experiments on the Dunbar, Coxville, Portsmouth, Appling, and Davidson soils. It had no unfavorable effect on the Norfolk sandy loam or Norfolk fine sandy loam, or on the Cecil clay, Marlboro sandy loam, or Marlboro fine sandy loam.

In experiments with some of the soils, noticeably the Dunbar and Portsmouth, the mixtures supplying 94 pounds of chlorine per acre gave larger yields than mixtures containing no chlorine.

In the experiments on the Greenville sandy loam at Weldon, N. C., and on the Marlboro fine sandy loam at Seaboard, N. C., where 1,200 pounds per acre of 6–8–4 fertilizer were applied, 188 pounds per acre of chlorine were supplied where the muriate of potash was used

[4]Fertilizer ratio stated in order of ammonia, phosphoric acid, and potash.

TABLE 3.—*Effect of fertilizers containing varying amounts of chlorine from ammonium chloride and potassium chloride on yield of cotton on nine Coastal Plain soils.*

Soil type and location	Year	Fertilizer analysis* (NH_3-P_2O_5-K_2O)	Pounds of fertilizer per acre	I		II		III	
				Ammonium chloride and potassium chloride sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	Pounds of seed cotton per acre	Ammonium chloride and potassium sulfate sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	Pounds of seed cotton per acre	Ammonium nitrate and potassium sulfate sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	Pounds of seed cotton per acre
Dunbar fine sandy loam, New Bern, N. C.	1920	5-7-4	900	123	950	94	1,152	0	930
Coxville sandy loam, New Bern, N. C.	1920	5-7-4	900	123	708	94	786	0	700
Portsmouth sandy loam, New Bern, N. C.	1921	6-8-4	900	141	1,420	112	1,574	0	1,724
Portsmouth sandy loam, New Bern, N. C.	1922	6-8-4	900	141	300	112	460	0	620
Marlboro sandy loam, Wilson, N. C.	1926	6-8-4	900	141	1,247	112	1,291	0	1,276
Marlboro sandy loam, Wilson, N. C.	1927	6-8-4	900	141	1,566	112	1,566	0	1,580
Marlboro fine sandy loam, Seaboard, N. C.	1925	6-8-4	1,200	188	1,242	149	1,472	0	1,403
Greenville sandy loam, Weldon, N. C.	1926	6-8-4	1,200	188	1,250	149	1,410	0	2,130
Greenville sandy loam, Weldon, N. C.	1927	6-8-4	1,200	188	1,240	149	1,420	0	1,900
Norfolk sandy loam, Darlington, S. C.	1924	6-8-4	900	141	1,180	112	1,040	0	1,140
Marlboro fine sandy loam, Bennettsville, S. C.	1923	6-8-4	900	141	1,380	112	1,220	0	1,260
Norfolk fine sandy loam, Florence, S. C.	1923	6-8-4	900	141	1,160	112	1,070	0	1,370
Norfolk fine sandy loam, Florence, S. C.	1924	6-8-4	900	141	500	112	610	0	680
Norfolk fine sandy loam, Florence, S. C.	1925	6-8-4	900	141	1,320	112	1,280	0	1,380

*Phosphoric acid in fertilizer from superphosphate; nitrogen and potash as noted.

TABLE 4.—*Effect of fertilizers containing varying amounts of chlorine from ammonium chloride and potassium chloride on yield of cotton on three Piedmont soils.*

Soil type and location	Year	Fertilizer analysis* (NH_3-P_2O_5-K_2O)	Pounds of fertilizer per acre	I: Ammonium chloride and potassium chloride sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	I: Pounds of seed cotton per acre	II: Ammonium chloride and potassium sulfate sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	II: Pounds of seed cotton per acre	III: Ammonium nitrate and potassium sulfate sources of N and K_2O in fertilizer. Pounds of chlorine supplied per acre	III: Pounds of seed cotton per acre
Cecil clay, Shelby, N. C.	1924	6-8-4	900	141	1,204	112	1,054	0	1,160
Cecil clay, Shelby, N. C.	1925	6-8-4	900	141	725	112	754	0	754
Appling sandy loam, Kings Mt., N. C.	1926	6-8-4	900	141	938	112	1,088	0	1,163
Davidson Clay, Lexington, N. C.	1926	6-8-4	900	141	1,110	112	1,200	0	1,245
Davidson Clay, Lexington, N. C.	1927	6-8-4	900	141	1,260	112	1,520	0	1,470

*Phosphoric acid in fertilizer from superphosphate; nitrogen and potash as noted.

and 149 pounds in the sulfate of potash mixture. There was a marked reduction in yield from the muriate of potash mixtures on both soils, and from the result with the ammonium nitrate mixture on the Greenville soil it might be concluded that the mixture of ammonium chloride with potassium sulfate, supplying 149 pounds of chlorine per acre, was harmful.

SUMMARY AND DISCUSSION

Potassium chloride as a source of potash in mixed fertilizers for cotton in the Coastal Plain and Piedmont Region of the southeastern states is as good a form of potash as potassium sulfate, as shown by data secured in experiments on many soil types reported in this paper.

Kainit has not shown up altogether as favorably as the muriate and sulfate of potash. In so far as the effect of chlorine supplied in potassium chloride is concerned, there appears no liklihood that this will become an unfavorable factor. Nine hundred pounds per acre of a 4% potash mixture, which is more than is used by cotton growers generally, if made from potassium chloride, supplies 29 pounds per acre of chlorine. From these experiments, larger quantities of this element can be supplied in the fertilizer without unfavorable effects to cotton. As much as 112 pounds per acre were supplied without unfavorable results and larger applications on some soil caused no retardation of growth or reduction in yield. Nine hundred pounds of an 8% potash mixture, made from potassium chloride, would supply only 58 pounds per acre of chlorine, while the same amount of a 12% potash mixture supplies 87 pounds of chlorine per acre. The latter is considerably below the zone of probable injury from chlorine, unless some very unusual soil conditions exist. Nine hundred pounds per acre of a 4% potash fertilizer made from kainit supplies 118 pounds of chlorine which seems near the limit of chlorine endurance for cotton, in most soils, as indicated by these experiments.

The cotton plant is apparently not as sensitive to chlorine effects as the tobacco plant. Garner, *et al.* (2) have recently shown that adverse nutritional effects and retarded growth of tobacco may result from considerably less than 100 pounds of chlorine per acre applied in the fertilizers, and in some cases considerable injury has resulted from 40 to 60 pounds per acre. The intensity of the effects vary with soil and climatic conditions.

In the compounding of fertilizers, especially when pure chemical salts are used, it is desirable to include a variety of plant food elements, and to avoid an excess of any one element. From this point of

view, it would not seem good practice to have the entire source of potash and nitrogen in a fertilizer mixture derived from muriate of potash and ammonium chloride. There are indications that the amount of chlorine supplied by the two salts when used in a mixed fertilizer applied at the rate of 900 pounds per acre is excessive for best growth and yield of cotton.

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NITROGEN FIXATION BY *RHIZOBIUM MELILOTI* AND *RHIZOBIUM JAPONICUM*[1]

G. GORDON POHLMAN[2]

The discovery that the bacteria present in the nodules of leguminous plants were associated with the fixation of atmospheric nitrogen led to an extensive study of these organisms, both in the root nodules of the host plant and on nutrient media. It was believed at first that the bacteria were entirely responsible for the fixation, and that the host plant furnished only a plentiful supply of carbohydrates which served as a source of energy for the bacteria. Assuming this to be true, a number of early investigators tested the ability of the legume bacteria to fix nitrogen under artificial conditions, both in solutions and on solid media. Some of these investigators secured a fixation which was undoubtedly above the limit of experimental error. However, there were occasional results secured in which the increase in nitrogen content in the inoculated media was negligible.

In a recent article, Hopkins (3)[3] tabulated the results of 51 papers dealing with the question of nitrogen fixation in the absence of the host plant. Of these, 33 papers reported positive fixation, 15 no fixation, and 3 were uncertain and no conclusions were drawn regarding their results. In the same article the results of some nitrogen fixation studies in solutions containing small amounts of nitrogen were reported. The increase in nitrogen content of the solutions was very small and Hopkins concluded that no nitrogen was fixed under the conditions of the experiment.

Löhnis (4) and Allison (1) have likewise reported negative results in nitrogen fixation studies in the absence of the host plant. As a result of gasometric studies, Burk (2) concluded that the legume bacteria could not fix nitrogen in the absence of the host plant.

Various explanations have been advanced for the differences in the results obtained. The purity of the cultures employed is sometimes doubtful, and undoubtedly some of the earlier results are questionable for this reason. Others are of little significance because of faulty methods of analysis. But many of the results have been secured under carefully controlled conditions and the fixation, although small, appears to be above the limit of experimental error. There is then, still some question regarding the ability of *Rhizobium* to fix nitrogen

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[3]Reference by number is to "Literature Cited," p. 27.

in the absence of the host plant. The work reported here was undertaken in an attempt to help clarify the problem.

EXPERIMENTAL

At the present time there is no means of determining exactly the chemical compounds present in the roots of the leguminous plants, and of duplicating them in the proper proportions in laboratory media. The cells of the roots are composed of carbonaceous material, probably largely carbohydrates, which, according to our present theory, furnish the energy for the activity of the nodule bacteria. It is quite apparent from the results of the nitrogen fixation studies which have been made that the bacteria present in the roots utilize the energy secured there much more efficiently, that is more nitrogen is fixed per unit of energy, than under any of the conditions in which they have been tested. However, we have no means of knowing whether the energy is furnished by several different organic compounds, or whether it is furnished principally by one particular compound. Nor do we know that this energy is furnished by a nitrogen-free substance. Inasmuch as the roots of the legumes are rich in nitrogenous compounds, it is possible that these may be directly involved in the process of fixation.

The presence of enzymes in the roots may also be of importance in the process. Although the possibility of the fixation by the action of co-enzymes has been suggested, no attempts have been made to secure these enzymes in the artificial media which have been employed.

The first series of experiments was planned to determine the effect of the energy source upon the fixation of nitrogen. The basic medium used consisted of

Carbohydrate	10.0 grams	$FeCl_3$	trace
K_2HPO_4	0.5 gram	$MnSO_4$	trace
$MgSO_4$	0.2 gram	$CaCO_3$	3.0 grams
NaCl	0.2 gram	Distilled water	1,000 cc

The carbohydrates used were sucrose, lactose, dextrose, maltose, soluble starch, inulin, galactose, and levulose. Mannitol, a polyhydric alcohol, was also tested.

One hundred cubic centimeter portions of the above media were placed in 500-cc Erlenmeyer flasks, sterilized, and inoculated. Two strains of *Rhizobium meliloti* and two strains of *Rhizobium japonicum* were tested. These organisms had previously been tested for ability to produce nodules and for purity on potato slants and in milk. After an incubation period of three weeks the entire sample was

taken for the nitrogen determination. Inasmuch as there were neither nitrates nor nitrites present, the total nitrogen was determined by a modified Kjeldahl method in which a salt mixture containing sodium sulfate, copper sulfate, and ferrous sulfate was added to hasten the digestion.

The results of these tests are shown in Table 1. With the exception of the media containing inulin and levulose, the solutions were all nitrogen-free, and the small amount of nitrogen present in the check solutions represents that present in the reagents used in the analyses. In a few of the tests, particularly those with soluble starch and inulin, there was very little growth as indicated by the lack of turbidity in the solutions.

TABLE 1.—*Nitrogen fixation by Rhizobium meliloti and Rhizobium japonicum in nitrogen-free media, with the results expressed as mgm of nitrogen per 100 cc of solution.*

Organism*	Energy source								
	Mannitol	Sucrose	Lactose	Dextrose	Maltose	Soluble starch	Inulin	Galactose	Levulose
Check	0.44	0.27	0.14	0.43	0.43	0.71	1.64	0.71	1.17
Check	0.58	0.71	0.86	0.29	0.43	0.36	1.36	0.86	0.78
Check	0.44	—	—	—	—	—	—	—	—
107	1.02	0.71	0.57	0.71	0.71	0.71	—	—	—
107	0.65	0.50	0.21	0.71	0.57	0.57	—	—	—
107	0.58	0.43	0.14	0.29	—	—	—	—	—
112	0.58	0.57	0.14	0.50	—	—	—	—	—
112	0.58	1.14	0.29	0.36	—	—	—	—	—
112	0.73	0.50	—	—	—	—	—	—	—
406	0.58	0.71	0.29	0.29	—	—	1.57	0.71	0.86
406	0.58	0.43	—	0.29	—	—	1.57	0.93	0.71
406	0.44	1.28	—	0.29	—	—	—	—	—
407	1.02	0.78	0.57	0.29	—	—	—	—	—
407	1.02	0.78	0.29	0.14	—	—	—	—	—
407	0.51	0.50	—	0.29	—	—	—	—	—

*107 and 112 are strains of *Rhizobium meliloti*, 406 and 407 are strains of *Rhizobium japonicum*.

The slight variation in the amount of nitrogen, although usually in favor of the inoculated solutions, was too small to be significant. Apparently the strains tested were unable to fix appreciable quantities of nitrogen under the conditions of the experiment.

A second series of experiments was outlined to determine the effect of the addition of soluble nitrogenous compounds upon the fixation of nitrogen. The basic medium was the same as in the previous experiments, except that mannitol was added as the energy source, and peptone, urea, asparagin, and yeast extract were added to

furnish nitrogen. The yeast extract was obtained by heating 100 grams of fresh starch-free yeast in 1,000 cc of water in flowing steam for 3 hours. The cells were then allowed to settle, the clear supernatant liquid decanted off, and the reaction adjusted to pH 6.8. The apparent growth, and especially the production of gum, was much more rapid in these solutions than in those containing no combined nitrogen. This was particularly noticeable in the solutions containing peptone and yeast extract. However, there was no appreciable fixation of nitrogen, as is shown in Table 2.

TABLE 2.—*Nitrogen fixation by Rhizobium meliloti and Rhizobium japonicum in media containing combined nitrogen with the results expressed as mgm of nitrogen per 100 cc of solution.*

Organism*	Nitrogen source					
	Yeast extract 100 cc per liter		Peptone 1.0 gram per liter		Asparagin 0.5 gram per liter	Urea 0.5 gram per liter
Check	3.78	3.20	14.7	14.6	11.20	25.60
Check	3.20	3.35	14.4	14.7	10.58	25.50
Check	3.78	3.13	15.1	14.7	——	26.20
107	3.78	3.35	15.9	14.7	11.06	19.04
107	3.64	3.20	14.6	15.0	10.92	16.64
107	3.64	3.35	15.2	——	——	20.28
112	3.78	3.13	15.0	14.7	11.34	19.64
112	3.78	3.20	14.9	14.4	——	19.04
112	3.20	3.20	14.85	14.6	——	——
406	3.57	3.28	14.85	14.7	——	22.76
406	3.50	3.13	14.3	14.0	——	21.84
406	3.64	3.13	14.4	13.7	——	23.08
407	3.78	3.50	14.85	14.4	10.36	23.08
407	3.50	3.35	14.6	14.7	10.36	23.40
407	3.78	3.20	15.0	14.4	——	21.84

*107 and 112 are strains of *Rhizobium meliloti*, 406 and 407 are strains of *Rhizobium japonicum*.

The loss of nitrogen in the inoculated urea solutions may have resulted from a volatilization of ammonia, as *Rhizobium* has been found to produce ammonia when grown in urea solutions. In all of the other tests the differences in the amount of nitrogen found were within experimental error.

A test of the ability of *Rhizobium meliloti* and *Rhizobium japonicum* to fix nitrogen when grown on solid media was also made. For this purpose silica gel plates, similar to those used in nitrogen fixation studies with *Azotobacter*, were used. In addition to the regular nutrients, 10 cc of yeast extract were added to each plate. Total nitrogen was determined after an incubation period of three weeks.

The results were as follows:

	Nitrogen in mgm
Check	3.82
Inoculated with *Rhizobium meliloti*	4.88
Inoculated with *Rhizobium meliloti*	4.84
Inoculated with *Rhizobium japonicum*	3.75
Inoculated with *Rhizobium japonicum*	3.75

There was a slight increase in the nitrogen content of the gel inoculated with *Rhizobium meliloti*. The growth on the medium seemed to be characteristic of this species, but there is the possibility that some other organisms capable of fixing nitrogen may have gained entrance during the three weeks' incubation period. It is probable, however, that the conditions of this experiment were much more favorable to the growth of the legume bacteria, inasmuch as they are aerobic organisms, and a larger fixation of nitrogen would probably take place, even as it does with the aerobic *Azotobacter* organisms under similar conditions. The amount of growth was much smaller on the gel inoculated with *Rhizobium japonicum*, and no increase in nitrogen content was found.

In order to test the effect of the enzymes present in the roots of the leguminous plants, an experiment was performed to test the nitrogen fixation by *Rhizobium japonicum* growing in a soybean root extract. This extract was prepared from the roots of young soybean plants. The roots were ground in a meat chopper, then mixed with three parts of water, and sterilized by passing through a Pasteur-Chamberlain filter candle. One hundred cubic centimeters of this clear sterile solution were placed in sterile flasks and inoculated in duplicate with two strains of *Rhizobium japonicum*. The analyses for total nitrogen after three weeks' incubation showed no increase in nitrogen content in any of the inoculated media.

DISCUSSION

Although the results reported here are largely negative, they do not prove that species of *Rhizobium* do not have the power to fix atmospheric nitrogen in the absence of the host plant. They only show that the proper conditions for the fixation of nitrogen were not provided. On the other hand, the fact that these bacteria are necessary in the legume plant for the fixation of atmospheric nitrogen does not prove that they alone are responsible for the fixation, but does indicate that they play some part in the process. It does seem probable, however, that certain species of *Rhizobium* may be able to fix appreciable quantities of nitrogen if they are cultivated under the proper conditions.

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THE DIRECT ISOLATION OF *RHIZOBIA* FROM SOIL[1]

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Although there can be no doubt that *Rhizobia* are present in soils where nodules are found on the leguminous plants, a uniformly successful method for the isolation of these organisms without the aid of the host plants has not been described.

Beijerinck (1)[3], reported the isolation of *Rhizobia* directly from a suspension of the soil in water. He stated that this was very difficult because of the small size and the indefinite cultural characteristics of the organism. The pea-extract, glucose, asparagin medium of Beijerinck was used by Nobbe, *et al.* (11), who state that they were able to isolate cultures of the root-nodule bacteria directly from soil in which the roots of peas, *Robinia*, *Cytisus*, and *Gleditschia* were growing. The culture from the pea soil was apparently the only one which formed nodules.

Mazé (9), reported an interesting attempt to isolate the nodule organism directly from the soil. He isolated a spore-former which he called bacillus *a*, which was transformed into bacillus *b* and *c*. He claimed the latter were two different forms of the nodule bacteria, although the cultural characteristics differed. Neither *a*, *b*, nor *c* formed nodules, but a mixture of *b* and *c* produced nodules on vetch. It is probable that this nodule formation was the result of contamination.

A medium claimed to be selective for *Rhizobia* was developed by Grieg-Smith (4). This medium was carefully studied by Kellerman and Leonard (7), and was found to show no special selectivity for the root-nodule organisms, and proved to be less selective than the congo-red agar described by Kellerman (6). Kellerman and Leonard (7), attempted to isolate the nodule bacteria directly from three types of soil, *viz.*, (a) soil used in potting plants at the U. S. Dept. of Agriculture greenhouses; (b) soil from Akron, Colorado, taken from the roots of *Astragulus falcatus* Lam. and known by check experiments to be able to inoculate the roots of *Astragalus sinicus* Linn.; and (c) soil from Ithaca, N. Y., which had been sterilized and inoculated with *B. radicicola* isolated from alfalfa nodules. From colonies supposedly pure, tests were made for the ability to form nodules on plants grown in special glass jars designed to prevent contamination. At the end of

[1]Contribution from the Department of Agricultural Bacteriology, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Received for publication August 23, 1930.

[2]Instructor and Associate Professor, respectively.

[3]Reference by number is to "Literature Cited," p. 31.

63 days the plants were removed from the jars and the roots carefully washed. Results were negative except in the case of the third soil.

Soil-extract, maltose agar was used by Lipman and Fowler (8), for plating soil which had previously grown *Vicia sicula*. From colonies which resembled *Rhizobia* in cultural characteristics, 44 transfers were made to slants of soil-extract agar. Twenty-one of these colonies were positive in nodule formation. Soil-extract-mannitol agar proved the best of the four media used by Joshi (5). All of the media, however, gave colonies other than *Rhizobia*. He reported the isolation of the *Rhizobium* species of *Crotolaria juncea, Cajanus indicus, Vigna catjung*, and *Phaseolus acontifolius* directly from the soil.

Vögel and Zipfel (12), isolated three cultures of the bean and four cultures of the pea organism directly from soil samples taken near the roots of the respective plants. The final identification of these cultures as root-nodule organisms was based entirely upon serological tests and not on plant tests. Müller and Stapp (10) used both liquid and solid media with little success.

The method reported here is based on a suggestion of Budinov (3), who used capillary tubes containing a selective medium and suspended in a water suspension of the soil for the direct isolation of the organism. He recorded the isolation of two organisms which agreed in their cultural characters with the nodule organism. Unfortunately, he gives no record of the nodule-forming ability of these cultures. Recent studies in this laboratory on Budinov's method with different media have shown that it is readily possible to isolate the root-nodule bacteria directly from the soil. Several media were tested and of these yeast-extract, mannitol[4] exerted the most selective chemotactic effects on *Rhizobium meliloti* and *Rhizobium trifolii*.

Capillary tubes of approximately 1 mm diameter and 50 to 60 mm in length were sealed at one end and autoclaved in a dish of the medium. These tubes, filled with the sterile medium, were then suspended through corks with the open end down in a water sus-

[4]Mannitol	10.0	grams
Dibasic potassium phosphate	0.5	gram
Magnesium sulfate	0.2	gram
Sodium chloride	0.2	gram
Calcium carbonate	3.0	grams
Yeast extract	100	cc
Distilled water	900	cc

The yeast extract is the supernatant liquid from an autoclaved 10% suspension (wet basis) of starch-free baker's yeast in water. For solid media 15 grams of agar were added per liter. Brom-thymol-blue, 5 cc of 0.5% alcoholic solution per liter, or congo red, 5 cc of a 0.25% aqueous solution per liter, were added to the agar for use in slant cultures.

pension (1–100) of the soil to be examined. The contents of one of these tubes were plated after one hour and others after 12 and 24 hours on brom-thymol-blue, yeast-extract, mannitol agar. The plates poured from the 12-hour capillary tubes showed the largest percentage of colonies resembling cultures of *Rhizobia*, frequently as high as 90%. Such colonies were picked and streaked upon differential media, brom-thymol-blue, yeast-extract, mannitol agar; congo-red, yeast-extract, mannitol agar; litmus milk; and potato slopes. Provisional identification as to the cross-inoculation group was made from the cultural characteristics. The cultures were then tested for ability to form nodules.

The plants used to confirm nodule formation were grown under bacteria-free conditions in 6-ounce glass bottles on Bryan's (2) nutrient solution to which 0.65% agar had been added. After the sterile seeds had germinated on the surface of the agar, 1 cc of a water suspension of the culture from the agar slant was added. The bottles were then placed in the greenhouse.

Frequently, practically all the colonies on plates made from fresh samples of soils taken from around the roots of leguminous plants were of *Rhizobium*. Even on air dry soils which had been stored in the laboratory for several months a large proportion of the colonies were of *Rhizobium*. Table 1 shows the results obtained from a study of four soils from Kentucky in which alfalfa and clover had been grown and of two obtained at Madison. The samples from Kentucky were examined about six months after being taken from the field.

TABLE 1.—*Isolation of Rhizobia directly from soil by the capillary tube method.*

Source of soil	Number of colonies picked	Identification				
		By cultural characteristics			By nodule formation	
		Contaminated cultures	Alfalfa nodule organism	Clover nodule organism	Alfalfa nodule organism	Clover nodule organism
Kentucky A	5	0	2	3	2	3
Kentucky B	6	1	5	0	5	0
Kentucky C	12	2	6	4	5	5
Kentucky D	6	1	3	2	3	2
Wisconsin A	24	7	0	17	0	15
Wisconsin B	25	4	7	15	7	13
Total.....	79	15	23	41	22	38

Of the 79 colonies picked from the plates because of their resemblance to the colonies of *Rhizobium*, 15 were discarded after

further cultural tests as they appeared to be contaminated. Approximately 94% of the remainder formed nodules on the appropriate host plants. The identification of the cultures as to cross-inoculation group by cultural tests was quite satisfactory. Twenty-three of the cultures were judged to be alfalfa nodule organisms by growth characters on laboratory media. All but one of these formed nodules on alfalfa, and the remaining culture formed nodules on clover. Of 41 cultures which reacted as clover nodule organisms on laboratory media, 37 formed nodules on clover. The other four did not form nodules on either clover or alfalfa.

The method is an interesting application of the principle of chemotaxis and provides a simple method of securing *Rhizobia* from the soil without passage through the host plant.

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A METHOD FOR THE GROWTH OF LEGUMINOUS PLANTS UNDER BACTERIOLOGICALLY CONTROLLED CONDITIONS[1]

E. W. Hopkins, P. W. Wilson, and E. B. Fred[2]

The culture of higher plants in the absence of micro-organisms has engaged the attention of plant physiologists, agronomists, and bacteriologists for many years. The importance of the exclusion of contaminating organisms in studies of plant physiology has led to the development of numerous methods for growing plants in an environment free of micro-organisms. This paper will not attempt the review of the voluminous literature on the subject since this has been done quite adequately by Klein and Kisser (4)[3] and by de Zeeuw (7). One even hesitates to add to this impressive array of devices that seek to keep out the ubiquitous organisms of the soil and air. However, many of the methods involve such complicated set-ups as to render them unsuitable for numerous experiments or ready manipulation, and others, with more simple arrangements, often fail to accomplish their purpose. The technic described in this paper contains features already noted in the literature, but certain modifications and additions have been developed which, it is thought, will be of value to other research workers.

The method used to grow the plants makes use of glass containers, closed with cotton plugs. It was found that the best results were obtained with bottles having small necks. However, this limits the applicability of the method to the smaller plants. The technic described has been developed and tested for small legumes, such as the clovers and alfalfa. For successful application to larger plants certain modifications would be necessary.

For discussion, the procedure can be divided into three sub-heads, *viz.*, (a) sterilization of the seed, (b) transfer and growth of plants in suitable containers, and (c) tests for sterility at the completion of the experiment. In this discussion "sterility" as applied to seeds or plants is used in the sense of freedom from micro-organisms as indicated by standard bacteriological tests.

[1]Contribution from the Departments of Agricultural Bacteriology, and Agricultural Chemistry, University of Wisconsin, Madison, Wis. Herman Frasch Foundation Research in Agricultural Chemistry Paper No. 12. Received for publication August 28, 1930.

[2]Research Fellows, and Professor of Agricultural Bacteriology, respectively.

[3]Reference by number is to "Literature Cited," p. 40.

EXPERIMENTAL

STERILIZATION OF SEED

After trial of a number of methods, the following procedure was adopted as being suitable for effective sterilization and minimum injury to the seed: The seeds were placed in a sterile petri dish and covered with 1 to 1,000 mercuric chloride solution. Intimate contact of the germicide with the seed was accomplished by placing the dish in a vacuum desiccator and evacuating for 5 minutes. The seeds were next washed twice under vacuum with sterile distilled water, and then covered with a modified Dakin's solution. This was prepared by diluting a sodium hypochlorite solution with a saturated solution of boric acid until the resulting solution contained 0.5% free chlorine as determined by the method of Dakin and Dunham (2). After 15 minutes exposure to this solution, the seeds were washed with sterile distilled water until the odor of chlorine could not be detected in the washings; this required five to eight rinsings. The seeds were then transferred to moist sterile blotting paper in petri dishes, placed in an incubator at 28°C, and allowed to germinate. This transfer was made in an inoculating chamber which will be described in detail under the second heading.

In this sterilization treatment, three substances with bactericidal properties were used for short periods of time. It was believed that in this way the maximum sterilization with the minimum injury to the seed could be attained. The percentage germination of sterilized seed was virtually equal to that of the untreated seed. In one experiment the germination in 24 hours was for non-sterile seed 75% and for sterilized seed 78%. Other experiments indicated that 90 to 95% of the viable seeds germinated after sterilization.

The efficacy of the sterilization was tested by transfer of 25 clover seedlings into tubes of (a) litmus milk; (b) yeast water-glucose, nutrient bouillion; (c) glucose-peptone broth; and (d) brain medium. The brain medium was made according to Hall (3) and was used for the detection of anaerobes. As controls on the method of testing, seedlings from untreated seed were also placed in the four media. For testing large numbers of seedlings, 2 cc of the medium placed in a 3-inch agglutination tube are most convenient. If the seedlings are to be planted after testing, this arrangement permits easy and rapid removal. In one test the check tubes of the unsterilized seedlings showed 100% growth in 48 hours. The sterilized seedlings were kept for 40 days with frequent observation. The glucose-peptone, the glucose-yeast water, and the brain media showed no signs of growth during this period and only two of the litmus milk tubes became coagulated.

During the incubation, the seedlings grew to be 6 to 7 cm in length and many developed the first true leaves. In experiments in which it is desired to test the individual seedlings before transfer to the culture flasks, a 48-hour incubation period is believed sufficient to show any contamination and does not allow the plant to grow to any appreciable extent. Also, this short time immersion in the test solution does not retard subsequent growth of the seedling. In actual practice a representative sample from each lot of sterilized seedlings is tested in glucose-yeast water at the time of transfer. After a year of these tests it has been found that the sterilization is 95 to 100% efficient as revealed by incubation of seedlings in litmus milk or glucose-yeast water. However, it must be remembered that these results were obtained for small seeds. With larger seeds it might be necessary to lengthen the time of exposure to the germicides in order to effect sterilization.

As a result of experiments on the sterilization of leguminous and cereal seeds with a number of commonly used germicidial agents, de Zeeuw (7) is of the opinion that seeds are seldom actually sterilized, but that antisepsis results from an incomplete removal of the disinfectant. Robinson (6) lends confirmation to this view by his observation that inoculation of sterilized legume seeds frequently fails to produce nodules on the plants. An attempt was made to determine if the sterility noted in our tests was due to the carrying over of the germicide into the test medium with consequent prevention of bacterial growth. In one experiment with sterilized clover seedlings the medium used for testing was inoculated with a loop of a 24-hour culture of *E. coli*. One hundred per cent growth was evidenced in these tubes in 24 hours.

In a second experiment an unsterilized clover seedling was placed in the tube with each sterile one. Again all tubes showed growth. In a third experiment 2 to 3 grams of clover seeds were sterilized and 25 seeds tested for sterility. The remaining seeds were then moistened with 1 cc of a suspension of *E. coli* containing about 10 million organisms. After thorough mixing the seeds were washed three times with sterile distilled water, and 25 were tested in glucose yeast water medium. In 24 hours all tubes showed growth, while the seeds taken before addition of the bacteria were incubated for 18 days without the appearance of growth. These experiments show that either the organisms are killed by the sterilization treatment or are no longer capable of growing since insufficient germicide was carried by the seed to prevent the development of added bacteria. Further evidence that the amount of germicide left on the seed is too small to

be of any consequence is the formation of nodules on plants grown from inoculated seedlings. In no case when the seeds were inoculated did nodules fail to form on the plants.

TRANSFER AND GROWTH OF PLANTS

The seedlings were transferred to bottles which contained modified Crone's agar (1) to a depth of about 5 cm. The containers used included 12-ounce flat bottles, 32-ounce round bottle, and test tubes 50 by 7 cm. It was found that even with the most careful technic, molds and bacteria appeared in the culture bottles after they were placed in the greenhouse. This was believed to be due in part to contamination incurred during transfer and inoculation of the seedlings. To obviate this source of contamination, a transfer and inoculation chamber was constructed

The details of the chamber are shown in Fig. 1. It is made of sheet copper provided with a window of single plate glass (A). Two open-

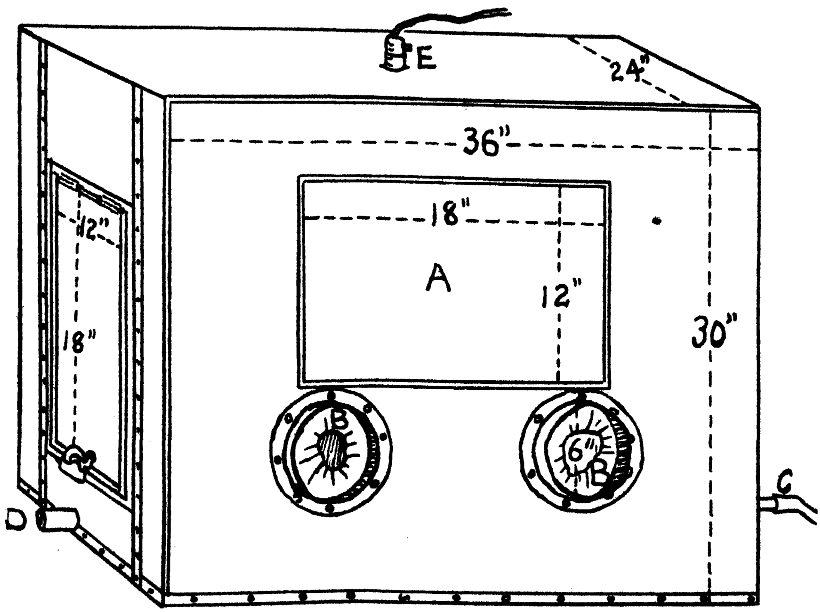

FIG. 1.—The inoculation chamber.

ings (B) give convenient access to the interior. These inlets are made with a removable flange which allows the insertion of a heavy cloth provided with elastic encircled arm holes, which fit snugly about the fore-arm. This flange affords protection against contamination and serves as a rest for the arm of the operator. During steaming these openings are tightly closed with removable copper

covers. An inlet tube (C) allows the chamber to be connected with a steam or gas supply. D is a drain, and E a tube in which an electric light is fitted. Each end of the chamber has a latched door that opens upward. The edges of these doors are flanged to fit into a narrow groove in which is placed rubber tubing of 4 mm diameter which insures a tight fit.

Before use, the chamber is thoroughly steamed for 30 to 45 minutes by connecting C with a convenient steam line. After cooling and drainage of the condensed steam, C is now attached to a gas supply and a microburner connected on the inside for the sterilization of loops, pipettes, etc.

The hands and arms of the operator are washed and sponged with a disinfecting solution before inserting them into the chamber. Any apparatus that cannot be left inside during the steaming is dipped in a bath of $HgCl_2$ (1 to 1,000) before placing in the chamber. Moisture is prevented from collecting on the window by the application of a mixture of 1 part alcohol and 3 parts glycerol. Inoculations made inside the chamber are performed most conveniently with Wright pipettes.

The efficiency of the apparatus in the reduction of contamination was tested by exposing three yeast water-glucose agar plates for 15 minutes while making transfers. One plate showed a single colony while the other two remained sterile. Plates exposed in the room at the same time showed an average of 6 colonies of molds and bacteria. In a second test no colonies appeared on the plates in the chamber while 12 developed on the three plates outside the chamber. To determine if steaming rendered the chamber free from living organisms, the chamber was sprayed with a heavy suspension of *Serratia fuchsina* and plates of beef peptone agar were then exposed for 10 minutes. After steaming for 30 minutes, plates were again exposed in the chamber and in the room. After 7 days incubation, the plates exposed before steaming were covered with the characteristic pink growth of Serratia, while those exposed after steaming averaged 1.3 colonies per plate, none of which were Serratia. Those exposed in the room averaged 19.7 colonies per plate. Further evidence of the value of the chamber was indicated by a noticeable decrease in mold contamination as compared with transfers made outside the chamber.

In spite of all these precautions in the sterilization of the seed and the transfer of the seedlings, contamination by mold and bacteria occasionally appeared in the culture bottles. This is not surprising in view of the fact that these bottles, protected only by a cotton plug, are left for two to three months in a greenhouse. By the use of the 12-

ounce bottles with small necks, closed with loose cotton plugs impregnated with $HgCl_2$ solution (1 to 1,000) and covered with small aluminum cups, this source of contamination has been reduced. It is more difficult to keep the wide-mouth round bottles and large test tubes free of foreign organisms. In such cases a sufficiently large number of bottles must be set up so that those showing contamination may be eliminated.

TEST FOR STERILITY AT THE COMPLETION OF THE EXPERIMENT

Probably the most important aspect of the entire problem is the application of an adequate means of detecting contamination in the supposedly sterile plant cultures at the conclusion of the growth period. Unfortunately this phase of the problem is often neglected; a tacit assumption is made that sterilization of the seed and medium will insure sterility throughout the experiment. Others apparently believe that mere observation constitutes a sufficient bacteriological assay. In the more carefully conducted experiments a plating of the substrate is often made. This method is probably dependable, but, due to the labor and the apparatus involved, it is seldom used in experiments embracing large numbers of cultures. Therefore it is desirable to have a test that will be at once rigorous and adaptable to experiments including a considerable number of units. Since agar was used in these experiments as a substrate for the plant cultures, active aerobic contamination would be present on the surface, and anaerobic contamination would be evident by the formation of gas bubbles in the agar. Several stabs made with a platinum wire into the agar of the plant cultures and inoculated into a suitable medium should serve as a means for the detection of foreign organisms. The medium selected as most suitable for the greatest variety of bacteria was litmus milk. Litmus milk has the added advantage that the root nodule bacteria produce a characteristic change (5) in this medium and may thus be easily differentiated from other forms.

As a check on the reliability of this method of testing sterility, 217 12-ounce bottles were planted with six unsterilized red clover seed in each bottle. Inoculation was made with a suspension of *Rhizobium trifolii* No. 200. After the plants had grown to such size that they filled the bottles, a platinum needle was stabbed into several places in the agar substrate, and litmus milk inoculated from the needle. Although non-sterile seeds had been used, the growth of contaminating organisms was apparent to the eye in only 30% of the bottles. Whereas the bottles gave very little evidence of visible contamination,

the litmus milk test revealed actual contamination in all but 3 cases out of the 217. The results of the test are depicted in Fig. 2. These experiments were accepted as evidence of the reliability of the method of determining sterility.

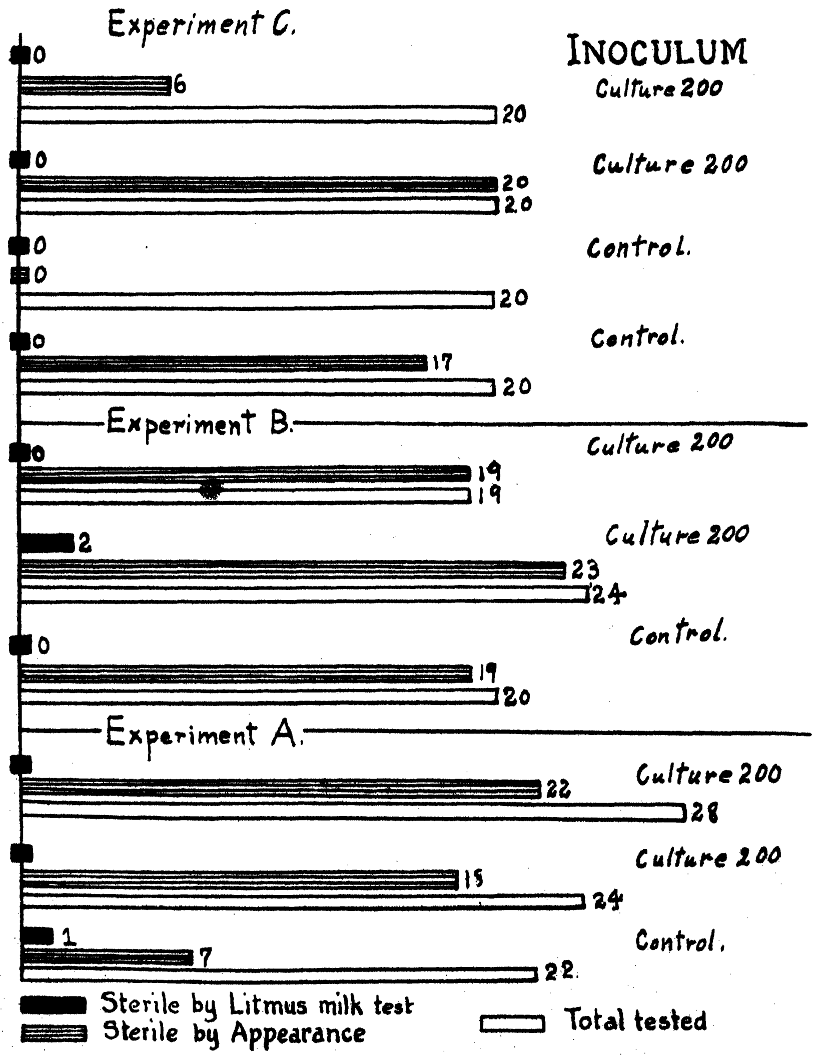

FIG. 2.—Bacteriological tests of plants grown in agar from unsterilized seed.

Red clover plant cultures were set up in 8-ounce bottles using the described technic. After two to three months growth in the greenhouse, all cultures were tested for sterility by the litmus milk test. Fig. 3 gives the results of these tests. In the inoculated bottles,

"sterile" means absence of organisms other than the nodule bacteria. These organisms produced their characteristic growth in all tubes of milk subcultured from bottles to which the organism had been added. The absence of other organisms is actual, and not a matter of

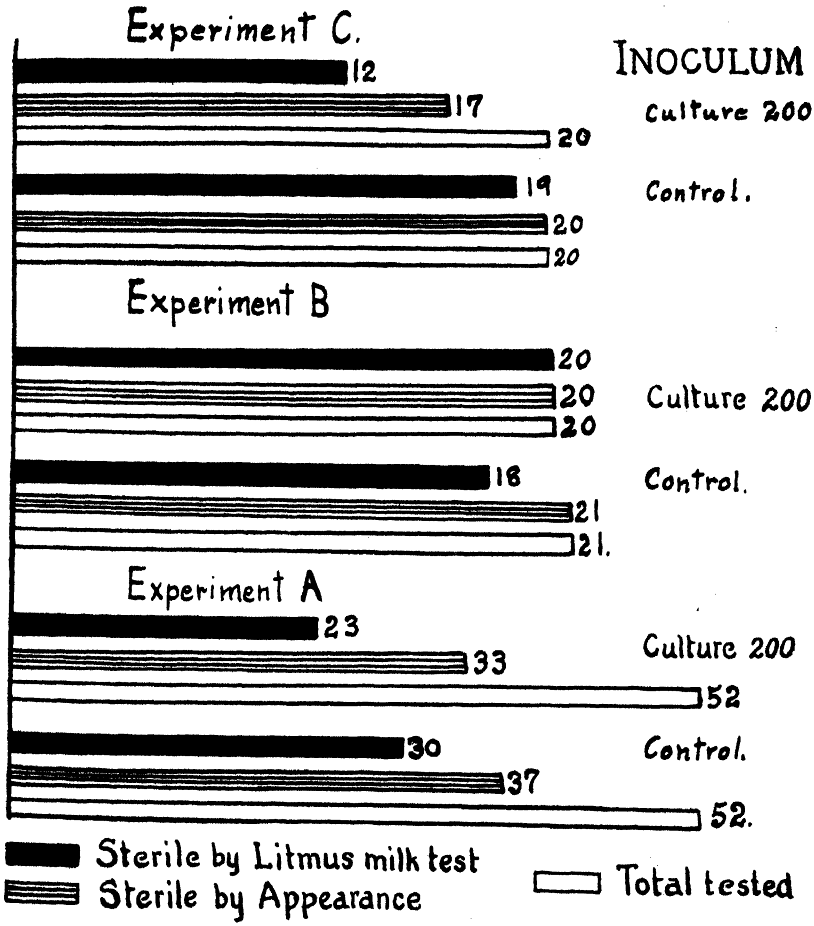

FIG. 3.—Bacteriological tests of plants grown in agar from sterilized seed.

suppression by the nodule organism. When other organisms are present changes are produced other than those typical of the nodule bacteria, as the data presented in Fig. 2 indicate. In the first experiment (A), 53 of the 104 bottles were found to be sterile at the end of the experiment. Later experiments (B and C), made after the technic had been more thoroughly mastered, showed 69 of the 81 bottles, or 85%, sterile at the end of a period of two to three months growth under greenhouse conditions. In other experiments, glucose

or a nitrogen source was added to the agar in which the plants were grown. Even with such favorable conditions for the development of contaminants, the presence of foreign organisms was detected in only about 5% of the cultures.

SUMMARY

A method is given for the sterilization of seed, a transfer chamber is described for use in planting, and a method outlined for testing the sterility of the plant cultures.

The seeds are sterilized by immersion in vacuo in 1 to 1,000 $HgCl_2$ solution for 5 minutes, and are then treated with a 0.5% sodium hypochlorite solution (modified Dakin's solution). The seeds are sprouted on moist sterile blotters in petri dishes or planted directly into cotton-plugged bottles containing nutrient salts and agar. The planting is done in a transfer chamber (description given), and a considerable amount of the contamination incident to transferring the seed is thus avoided. At the end of the experiment a test of the sterility of the plant cultures is made by inoculation of the culture medium into litmus milk. Such a bacteriological test of sterility is necessary, as mere observation is insufficient to detect contamination.

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WHEN TO TREAT QUACKGRASS MOST EFFECTIVELY WITH CHLORATES[1]

H. K. Rowley[2]

Chlorates have been used successfully to destroy quackgrass when careful and successive treatments have been made. The cost of eradicating large areas of quackgrass is too great, although extensive infestations may be prevented if proper treatments with chlorates are made while the infestation is yet confined to small areas or patches. Usually, quackgrass infestation starts from one or more plants which increase to form a mat. The underground stems are torn away by the cultivators and harrows and dragged to another part of the field where additional mats are formed. The experiment reported here was begun in 1929 to determine, if possible, the stage of growth at which quackgrass is most easily killed by chlorates (Table 1).

Table 1.—*Estimated percentage stand of quackgrass before and after treatment with sodium chlorate.*

Time of application	Stand before treatment, %	Stand after treatment, %
June	78.5	49.7
December	81.0	41.2
June and October	79.0	5.2
December and April	79.0	2.8

Fifty plats, each 6 x 6 feet, were laid off on a quackgrass infested field. The entire plat was treated with chlorate, but the estimated change in flora brought about by the treatment was based on a net area of 3 x 3 feet within each plat. The treatment consisted of an application of a 10% solution of sodium chlorate at the rate of 250 gallons per acre. Twenty plats received single applications of the solution, 10 in December and 10 in June. Twenty plats received double applications, 10 in December and April and 10 in June and October. The remaining 10 plats were left untreated to serve as checks. The stand of quackgrass in each plat was estimated in percentage before and after treatment with the chlorates.

[1]Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director. Received for publication September 10, 1930.

[2]Seed Analyst.

The single applications destroyed all of the parts of the quackgrass above ground, however, new parts sprang up from the underground stems. The June application decreased the stand of quackgrass on the average from 78.5% to 49.7%. The December application decreased the quackgrass from 81% to 41.2%. Although the plants surviving the treatments were not as large and thrifty as untreated plants, there remained, nevertheless, a heavy stand of quackgrass.

Double applications were very effective. The applications which were made in October and the following June showed on the average only 5.2% of a stand of quackgrass as compared with a stand of 79% before the two applications were made. The 10 plats which were treated in December and again in April showed on the average only 2.8% of a stand as compared with a stand of 79% before the treatments were made.

The December and April applications seemed to be slightly more effective than the June and October applications. The December and April applications were applied when the plants were dormant.

An interesting observation was made in the December and April treated plats. In these plats, where the eradication of quackgrass was almost complete, a very fine stand of Kentucky bluegrass appeared. The bluegrass was increased from a former stand of 17% to a stand of 53.8% at the end of the experiment. The growth of bluegrass, together with the absence of quackgrass, was quite conspicuous in these plats.

The June and October treated plats with an initial average stand of bluegrass of 17% were increased to a stand of 26.7%. The single treatment in June increased the stand of bluegrass on the average from 17% to 40.3%, and the single treatment in December showed an average increase in the stand of bluegrass from 19% to 45%.

SUMMARY

Data gathered from this experiment show that a single application of sodium chlorate at the rate of 250 gallons per acre does not free an infested field of quackgrass.

Two applications practically eradicated quackgrass whether they were made in June and October or December and April. However, the December and April treatment appeared to be somewhat more effective than the June and October treatment. This shows that quackgrass does not have to be in an active growing condition to be killed by chlorates. Applications made on dried tops were even slightly more effective than when made on green leaves and stems.

The sodium chlorate solution used at the rate reported in this experiment did not prove highly toxic to Kentucky bluegrass, particularly the December and April applications.

THE IMMEDIATE EFFECT OF FOREIGN POLLEN UPON THE KERNEL WEIGHT OF WHEAT (*TRITICUM VULGARE*)[1]

C. E. ROSENQUIST[2]

It has been known for a long time that foreign pollen often produces a visible effect on the F_1 hybrid seeds. In fact such results were so common in occurrence that a special name was needed for the phenomenon and Focke (3)[3] suggested the word xenia. Recent investigators, working with corn, have found that xenia is shown in the increased size of the crossed kernels when compared with selfed kernels if pure lines are used, or when compared with crossed kernels of the same variety if crosses of sub-species are used. The occurrence of this phenomenon in wheat was reported by Blaringhem (1) in 1913, and by Sax (7) and Griffee (4) in 1921.

The extent and magnitude of hybrid vigor in wheat crosses as revealed by xenia have not been fully demonstrated. In order to study further the effect of xenia on the F_1 hybrid kernels of wheat crosses, a relatively large number of crossed and selfed kernels was produced for comparison. By F_1 hybrid or crossed kernels is meant the kernels resulting directly from the process of crossing. The results reported in this paper were obtained from a study of 5,730 crossed and 7,528 selfed kernels produced during the 3-year period 1927–29.

METHODS

PRODUCING THE CROSSED AND SELFED KERNELS

The "approach" method of Jelinek (5) and Rosenquist (6) was used in all cases when producing the crossed kernels. The first crossed seeds produced (1926 and 1927) were quite small due to the fact that the outer glumes and lemmas were pulled off and the palea cut just above the stigmas. After emasculation the treated spike was fastened to the spike used as the male, which was treated in the same way but not emasculated. The male spike was always placed slightly above the female to allow the pollen to fall upon the stigmas. Two treated florets were left at each rachis joint or node. After covering both spikes with a paper bag the whole was shaken slightly two or three times a day for several days to aid in distributing the pollen. A large number of crossed kernels was produced per spike by this method

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication September 11, 1930.

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[3]Reference by number is to "Literature Cited," p. 63.

The next year (1928) a slight change in method was used which allowed the production of larger kernels of both crossed and selfed material. Instead of pulling off the lemmas they were merely cut off just above the stigmas. Again, the same method was followed for producing both crossed and selfed kernels so that their size would be comparable so far as methods were concerned.

Since there was great variation in the sizes of kernels produced upon different spikes, even though taken from the same plant, attempts were made to produce successfully both crossed and selfed kernels upon the same spike in order to make them more comparable. After several unsuccessful attempts a very satisfactory method was evolved. The outer glumes and extra florets were removed from each spikelet on one side of the spike, leaving at each rachis joint two florets which were then emasculated. The lemmas and paleas, however, were left intact. The same procedure, but without emasculation, was followed for the opposite side of the same spike but across the tips of each set of two florets a small size O. K. paper clip was fastened in such a way that the glumes were clipped shut and were unable to open until the clip was removed, which was 8 or 9 days later. By the time the clips were removed all pollen was shed and the anthers were shrivelled and dry, but the developing ovary had not as yet pressed against the closed end of the flower. About 2 days after emasculation the opposite side of the treated spike was crossed by the approach method (Fig. 1).

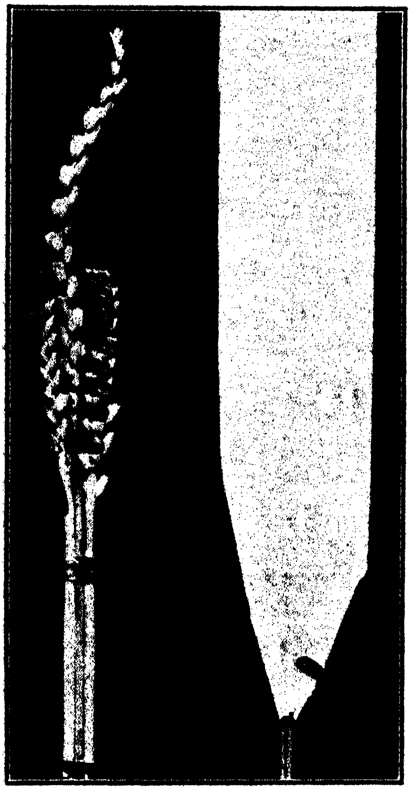

FIG. 1.—At the left is shown the method of fastening the culms together placing the male spike (without clips) slightly higher than the female spikes. The side of the spike without clips attached produced the crossed kernels. Selfed kernels were produced by florets which were closed by these clips. At the right is shown the method of covering the spikes to prevent the entrance of other pollen.

SELFING VS. INCROSSING

Since selfed seed, treated like incrossed seed but selfed instead of crossed, was used in these experiments, it becomes necessary to know how selfed compares with incrossed seed. Griffee (4) in his comparisons used "incrossed," i. e., crossed with pollen from plants of the same pure line, seed of the female parent. The only difference between selfing and incrossing is the emasculation and pollen application necessary to incrossing. A test was made in 1927 in which all of the outer glumes, extra florets, and lemmas were removed from seven spikes. The florets on one side of each spike were emasculated while those on the other side were selfed. The emasculated florets were then incrossed and the two types of kernels produced upon the same spike were compared. The average weight of the 58 selfed kernels was 16.7 mgm and that of the 31 incrossed kernels 15.5 mgm which is an increase in weight of 1.2 mgm, or 7% in favor of the selfed kernels, with odds of 2.1:1.

In 1929 a test was conducted to ascertain the difference between selfed and incrossed kernels produced on the same spike when the outer glumes and extra florets were removed and the inner glumes cut off above the stigmas. Twenty spikes produced 163 selfed kernels and 119 incrossed kernels. The selfed kernels produced on one side of the spikes averaged 1.2 mgm (6%) heavier than the incrossed kernels produced on the other side of the same spikes, with odds of 3.0:1.

Another test, similar to the above but in which spikes were used all of the kernels of which were selfed or all incrossed, was conducted in 1929. The 169 selfed kernels produced by 15 spikes averaged 0.1 mgm (0.6%) larger than the 166 incrossed kernels produced by 18 spikes, with no odds. For these two methods of producing selfed kernels there was no significant difference which could be attributed to manipulation between the selfed and incrossed kernels.

Further data comparing selfed with incrossed kernels are presented in Table 1. For the material reviewed in this table the selfed kernels were produced by closing the glumes tightly together with clips, while the incrossed kernels were produced by removing the outer glumes and extra florets. The "selfed" kernels were produced on one side of the spike, while the incrossed kernels were produced on the other side of the spike. Thirty treated spikes of winter wheat produced 159 selfed and 132 incrossed kernels, while 32 spikes of spring wheat produced 211 selfed and 160 incrossed kernels. The 12% decrease in size of incrossed over selfed kernels among the spring wheat lines studied is mathematically significant, but the 1.6% decrease among winter wheats is not.

TABLE 1.—*Comparison, by Student's method, between the average weights of kernels produced by the "incrossed" side and those produced by the selfed side of the same spike, using several lines of both spring and winter wheats, 1929.*

Seed types	No. of spikes	Average No. kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of incrossed over selfed kernels with odds
Winter wheat:				
Selfed......	30	5.3	18.9	—0.3 with odds
Incrossed...	30	4.4	18.6	of 3.6:1
Spring wheat:				
Selfed......	32	6.6	19.1	—2.3 with odds
Incrossed...	32	5.0	16.8	of 666:1

In general, taking the data comparing selfed with incrossed kernels as a whole, there was very little difference between their average weights, only about 5% in favor of the selfed kernels, and in few cases was this difference significant. In using selfed kernels then, in comparison with crossed kernels, the fact that the selfed kernels are slightly heavier than the crossed kernels, due to the depressing effects of the crossing process, should be taken into consideration.

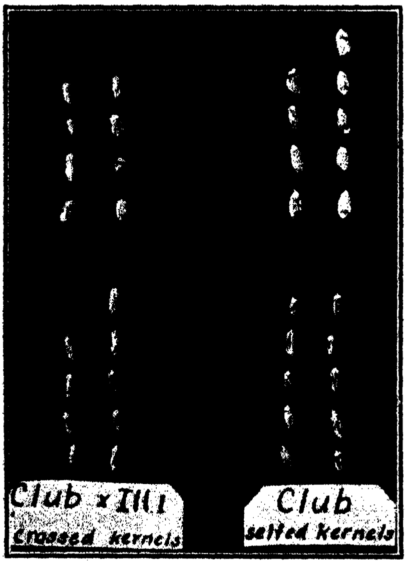

FIG. 2.—A glance at the crossed kernels in this photograph shows that they are more variable in size than the selfed kernels on the opposite side of the figure. The crossed and selfed kernels from these two spikes represent quite well the average condition for kernels obtained by the "clip" method of producing selfed and crossed kernels on the same spike.

That the process of crossing decreases the resulting kernel weight somewhat has been shown. Is this decrease due to the crossing process or to some other cause related to that process, as, for example, the relatively late fertilization of some of the eggs in the emasculated flowers? The writer is of the opinion that late fertilization of some of the eggs accounted for practically all of the decrease in kernel weight shown, since pollen may not fall on some stigmas until 2 or 3 days after most of the selfed material has been fertilized. Eggs fertilized relatively late would have a

shorter time in which to mature and would, as a consequence, produce smaller kernels than the average.

Fig. 2 shows the kernels produced upon the crossed side (left) and the selfed side (right), respectively, of two different spikes which were the same spikes shown in Fig. 1.

ERROR DUE TO SELFING AND POLLINATION WITH FOREIGN POLLEN

Unless great care is taken during the processes of emasculation and crossing considerable error may enter into the experiment due to accidental selfing or fertilization with foreign pollen. The crosses used in these experiments were planned in such a way that selfed plants as well as crosses due to foreign pollen could be detected in the F_1 generation. In 1927, no non-typical plants were found in a population of 171 F_1 plants. Only 0.8% in 1928 and 1.1% in 1929 of an F_1 population of 245 and 1,336 plants, respectively, were non-typical. In 1930, only 0.6% of the plants from crossed seed produced in the greenhouse were found to be non-typical when the 1,764 F_1 plants grown from these kernels were observed. The crossed kernels produced in the field, however, produced 882 F_1 plants, 3.4% of which were non-typical. This high percentage of non-typical plants is probably due to unusually strong winds and torrential rains which badly damaged or even completely removed the paper bags which covered the spikes. On the whole, however, only about 1% of the plants grown from F_1 crossed kernels were non-typical. This indicates about 1% of error due to selfing or fertilization with foreign pollen.

RESULTS

KERNELS PRODUCED ON DIFFERENT SPIKES

All of the data comparing crossed with selfed kernels of wheat presented by other investigators are based upon material produced upon different spikes. Some of the results presented in this paper are of that nature. The crossed and selfed kernels were produced by removing the outer glumes, lemmas, and extra florets and by cutting the paleas above the stigma. In Table 2 are included 19 different crosses, 8 of which produced increases and 11 of which produced decreases in the weight of crossed as compared to that of selfed kernels. As an average, the selfed kernels were 1.1 mgm (7%) heavier than the crossed kernels. No probable error was obtained for these data since the number of items was too small. The results of this experiment taken as a whole indicate no excess in weight of crossed over selfed kernels.

TABLE 2.—*Weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent, winter wheat, 1927.*

Material	No. of spikes	No. of kernels	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels
Selfed Hardy Northern	4	58	10.7	—
Hardy Northern x Nebr. 28 beardless	3	32	14.8	+4.1
Hardy Northern x Minturki	2	24	8.7	—2.0
Hardy Northern x Dawson Golden Chaff	1	12	8.1	—2.6
Hardy Northern x Michigan Amber	1	13	13.6	+2.9
Selfed Minnesota Reliable	4	49	17.3	—
Minn. Reliable x Mich. Amber	2	31	21.5	+4.2
Minn. Reliable x Nebr. 28 beardless	3	24	16.1	—1.2
Minn. Reliable x Fulhio	1	12	11.8	—5.5
Selfed Michigan Amber	8	212	15.3	—
Michigan Amber x Minturki	2	19	15.6	+0.3
Michigan Amber x Minn. Reliable	1	12	16.3	+1.0
Selfed Ilred	3	42	16.7	—
Ilred x Indiana Swamp Selection	3	24	15.7	—1.0
Selfed Ind. Swamp Selection	5	65	15.5	—
Indiana Swamp Sel. x Ilred	4	34	15.6	+0.1
Selfed Nebraska 28	3	50	13.8	—
Nebraska 28 x Red Cross	6	37	11.9	—1.9
Nebraska 28 x Fulcaster	4	50	13.3	—0.5
Nebraska 28 x Michigan Amber	1	14	15.4	+1.6
Selfed Minturki	7	134	15.3	—
Minturki x Michigan Amber	2	32	12.7	—2.6
Minturki x Fulhio	2	26	10.1	—5.2
Minturki x Hardy Northern	1	16	16.1	+0.8
Selfed Nebraska 28 beardless	6	110	15.9	—
Nebr. 28 beardless x Minn. Reliable	4	19	14.5	—1.5
Nebr. 28 beardless x Minturki	2	28	13.0	—2.9
Averages: Selfed	5.0	90.0	15.1	
Crossed	2.4	24.1	14.0	—1.1

Crossed and selfed kernels were produced upon different spikes in 1928 by cutting off the lemma and palea above the stigma. They differed from kernels produced in 1927 by being almost inclosed in the inner glumes. Table 3 presents a summary of the results with winter wheat comparing crossed with selfed kernels by averaging four or more spikes. In obtaining the averages presented, 103 "selfed"

spikes producing 2,649 selfed kernels and 147 "crossed" spikes producing 2,202 crossed kernels were used. Of the 28 crosses included in this table, 7 (involving 33 spikes) showed an increase in weight of crossed over selfed kernels, while 21 crosses (involving 125 spikes) showed a decrease in the crossed kernels. Two crosses showed a significant increase of crossed over selfed kernels, while seven showed a significant decrease. Of the seven crosses showing significant decreases in weight of crossed kernels when compared with selfed kernels, four involved Hardy Northern as the female parent and one as the male parent.

A very interesting exception to the unfavorable results shown by Hardy Northern in decreasing kernel weight in the F_1 seeds was shown by one of the same crosses, i. e., Hardy Northern x Red Cross, which was produced in the greenhouse while all the other crosses were produced in the field. The F_1 kernels of this cross when produced in the field were significantly smaller than the selfed kernels. Only three plants of each line were used in the greenhouse when producing the crossed seed, and, since a large amount of crossed seed for planting purposes was desired, the main spike as well as the second and third spikes were used to produce the crossed seed while the selfed seed had to be produced upon later and smaller spikes. As a consequence, the selfed kernels were relatively much smaller than the crossed kernels, since, according to Engledow (2), spikes from later tillers are progressively smaller than the main spike and also produce progressively smaller kernels.

The exceptional results of the other cross, Wheedling x Ilred, showing significant odds that crossed kernels were heavier than selfed, may be explained in the same manner as the first one mentioned. Though the cross was made in the field, few plants of Wheedling survived the winter. Consequently, considerable selection was inadvertently carried on in order that sufficient crossed seed might be first produced before spikes were treated for selfing. Thus the largest spikes were likely used for crossing with Ilred. These exceptions accentuate the necessity of including for comparison as nearly as possible a random sample of kernels or of spikes produced upon different plants.

The seven crosses shown in Table 3 which gave increases in crossed over selfed kernels produced an average increase of 2.0 mgm, while the 21 crosses which gave decreases in crossed as compared with selfed kernels produced an average decrease of 2.9 mgm. The average weight of all crossed kernels compared with that of all selfed kernels produced on different spikes of winter wheat in 1928 showed a 10% difference in favor of the selfed kernels.

TABLE 3.—*Weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent, winter wheat, 1928.*

Material	No. of spikes	Ave. No. kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels	Odds*
Selfed Ind. Swamp Sel. No. 3	6	33.2	21.4	———	———
Ind. Swamp Sel. x Ilred	4	16.8	22.9	+1.5±1.26	1.39:1
Ind. Swamp Sel. x Michikof	7	11.0	19.2	—2.2±1.28	2.98:1
Ind. Swamp Sel. x Wheedling	4	12.7	20.0	—1.4±1.15	1.39:1
Selfed Wisconsin 18	7	34.0	20.0	———	———
Wisconsin 18 x Michikof	8	14.5	17.9	—2.1±.89	8.48:1
Wisconsin 18 x Nebr. 28 beardless	4	10.3	17.4	—2.6±1.07	8.48:1
Selfed Michikof	20	25.1	21.5	———	———
Michikof x Minturki	10	13.0	18.9	—2.6±1.01	11.58:1
Michikof x Hardy Northern	14	14.5	18.3	—3.2±.98	37.46:1
Michikof x Ind. Swamp Sel.	3	16.7	19.0	—2.5	———
Michikof x Wisconsin 18	1	18.0	17.9	—3.6	———
Selfed Minturki	12	24.5	18.5	———	———
Minturki x Nebr. 28 bdls.	5	14.5	18.6	+0.1±1.02	1.00:1
Minturki x Michikof	2	20.0	18.4	—0.1	———
Minturki x Wheedling	2	9.0	18.6	+0.1	———
Selfed Hardy Northern	11	28.0	18.4	———	———
Hardy Northern x Ind. Swamp Sel.	6	15.3	14.0	—4.4±.70	19,230:1
Hardy Northern x Michikof	17	15.9	14.3	—4.1±.66	19,230:1
Hardy Northern x Wheedling	8	13.9	12.7	—5.7±.97	19,230:1
Hardy Northern x Red Cross	4	12.8	11.2	—7.2±1.12	19,230:1
Selfed Minnesota Reliable	6	25.3	17.7	———	———
Minn. Reliable x Nebr. 28 beardless	5	15.2	16.8	—0.9±.57	2.57:1
Selfed Indiana Swamp Selection	9	31.0	18.8	———	———
Ind. Swamp Sel. x Ilred	13	14.2	16.9	—1.9±.53	64.79:1
Ind. Swamp Sel. x Wheedling	4	18.3	23.7	+4.9±1.92	11.58:1
Ind. Swamp Sel. x Red Cross	2	19.5	18.6	—0.2	———
Selfed Wheedling	9	21.7	15.6	———	———
Wheedling x Ilred	5	15.0	18.2	+2.6±.73	64.79:1
Wheedling x Indiana Swamp	4	10.5	12.3	—3.3±.76	267.10:1
Selfed Nebraska 28	5	20.6	16.2	———	———
Nebraska 28 x Red Cross	5	13.4	17.5	+1.3±1.15	1.18:1

*Odds calculated only upon data involving more than three spikes.

TABLE 3.—*Concluded.*

Material	No. of spikes	Ave. No. kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels	Odds*
Selfed Nebraska 28 beardless	6	30.8	19.9	———	———
Nebr. 28 beardless x Minn. Reliable	6	13.8	17.3	—2.6±1.32	4.64:1
Selfed Hardy Northern	6	10.3	13.3	———	———
Hardy Northern x Red Cross	8	7.9	17.1	+3.8±.91	215.92:1
Selfed Red Cross	4	27.5	21.0	———	———
Red Cross x Ilred	2	18.0	15.3	—5.7	———
Red Cross x Nebr. 28	3	19.0	16.8	—4.2	———
Selfed Ilred	2	26.5	21.9	———	———
Ilred x Indiana Swamp Sel.	2	21.5	21.3	—0.6	———
Averages: Selfed	7.9	25.6	19.3	———	———
Crossed	5.6	13.9	17.3	—2.0	

*Odds calculated only upon data involving more than three spikes.

In general, decreases in average weight of crossed kernels below that of selfed kernels were more pronounced and more frequent in occurrence than were increases. The data resembled those comparing selfed with incrossed kernels, in that no appreciable increase in crossed over selfed kernels was indicated.

TABLE 4.—*Weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent, spring wheat, 1928.*

Material	No. of spikes	Ave. No. kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels	Odds
Selfed Illinois 1	11	18.9	19.2	———	———
Illinois 1 x Club	12	20.1	15.7	—3.5±1.00	53.9:1
Selfed Club	6	23.6	15.9	———	———
Club x Illinois 1	4	9.5	15.3	—0.6+1.00	no odds
Selfed Garnet	11	18.9	16.4	———	———
Garnet x Prelude	13	9.9	12.9	—3.5± .80	332.3:1
Selfed Prelude	23	16.0	12.6	———	———
Prelude x Garnet	14	7.4	9.5	—3.1± .60	1,350.0:1
Averages: Selfed	12.8	17.7	15.5	———	
Crossed	10.8	11.9	13.6	—1.9	

A test exactly the same as that described above was carried out with spring wheats. The results obtained are presented in Table 4. A total of 94 spikes, producing 905 selfed and 511 crossed kernels, was used in obtaining the averages presented in this table. Of the four crosses, all showed a decrease in crossed when compared with selfed kernels, three of which gave significant odds. The average decrease was 1.9 mgm, or about 12%. These data are quite similar to those for winter wheat in showing a decrease in crossed when compared with selfed kernels.

The large amount of material used in these experiments is worthy of mention. There were 51 crosses used, 15 of which, including only 11% of the total number of crossed spikes, produced increases in weight of crossed over selfed kernels. These 51 crosses involved 429 spikes which produced 4,274 selfed and 3,172 crossed kernels. Crossed kernels were, as an average, about 10% smaller than selfed kernels.

KERNELS PRODUCED ON THE SAME SPIKE

Realizing that variations in average kernel weight from spikes produced on the same plant as well as those produced on different plants are important enough to distort appreciably the data used in comparing crossed with selfed kernels, the writer devised a method of producing both crossed and selfed kernels on the same spike. This method was explained above in the section dealing with methods. A comparison of crossed with selfed kernels of winter wheat produced by the above method in 1929, is presented in Table 5. For obtaining the odds, Student's method was used. When one compares crossed kernels produced on one side of the spike with selfed kernels produced on the other side, it is apparent that only 2 of the 14 crosses produced crossed kernels which were heavier than selfed kernels, with odds so low as to suggest no appreciable difference. Of the 12 crosses showing a decrease in weight of crossed as compared with selfed kernels, 4 showed a significant decrease. All four of these included Michikof as one parent and this fact may indicate a depressing influence exerted by this line. As an average of all kernel weights shown in this table the crossed kernels showed a decrease of 0.6 mgm. A total of 168 spikes producing 1,046 selfed and 713 crossed kernels was used in obtaining this average difference. The differences shown by this experiment are very similar to those shown when selfed kernels are compared with incrossed kernels and are probably due to the same causes. No hybrid vigor was shown by the average kernel weights of any of the crossed seeds included in this table.

TABLE 5.—*Comparison between average weights of kernels produced by the crossed side and those produced by the selfed side of the same spike, winter wheats, 1929.*

Material	Number of spikes	Average number kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels, with odds
Selfed Nebraska 28	26	6.1	20.2	—0.6 with
Nebr. 28 x Minnesota Reliable	26	5.9	19.6	odds 3.8:1
Selfed Nebraska 28	8	7.4	21.5	+1.0 with
Nebraska 28 x Minturki	8	8.6	22.5	odds 3.1:1
Selfed Nebraska 28	4	5.7	20.0	+1.0 with
Nebraska 28 x Ind. Swamp Sel.	4	6.2	21.0	no odds
Selfed Nebraska 28	4	7.2	19.5	—0.3 with
Nebraska 28 x Hardy Northern	4	8.5	19.2	odds 1.3:1
Selfed Minnesota Reliable	37	5.4	17.6	—0.2 with
Minnesota Reliable x Nebr. 28	37	3.1	17.4	odds 7.6:1
Selfed Michikof	10	3.6	16.6	—1.5 with
Michikof x Hardy Northern	10	3.5	15.1	odds 4.0:1
Selfed Michikof	11	4.6	17.4	—1.5 with
Michikof x Minturki	11	3.8	15.9	odds 39.1:1
Selfed Indiana Swamp Sel	6	6.3	23.4	—3.9 with
Ind. Swamp Sel. x Wheedling	6	4.7	19.5	odds 2.1:1
Selfed Minturki	4	7.7	12.1	—0.3 with
Minturki x Nebraska 28	4	1.8	11.8	odds 2.4:1
Selfed Minturki	17	7.6	18.1	—2.2 with
Minturki x Michikof	17	4.6	15.9	odds 53.0:1
Selfed Ind. Swamp Sel. No. 3	13	7.8	23.2	—3.3 with
Ind. Swamp Sel. No. 3 x Michikof	13	4.2	19.9	odds 101.0:1
Selfed Ind. Swamp Sel	6	7.2	20.3	—0.7 with
Ind. Swamp Sel. x Wheedling	6	1.2	19.6	odds 2.1:1
Selfed Hardy Northern	8	6.7	17.4	—2.4 with
Hardy Northern x Michikof	8	2.8	15.0	odds 30.6:1
Selfed Ilred	4	5.8	19.5	—0.8 with
Ilred x Wheedling	4	2.0	18.7	odds 5.1:1
All other crosses combined:				
Selfed kernels	10	5.3	17.9	—0.7
Crossed kernels	10	3.4	17.2	
Averages: Selfed kernels	11.2	6.2	19.1	—0.6
Crossed kernels	11.2	4.2	18.5	

Table 6 presents a summary of the results obtained with spring wheat when crossed kernels are compared with selfed kernels pro-

duced on the same spike. Of the 20 crosses compared individually, only 1 gave results favoring crossed over selfed kernels and these were not significant. All others showed a decrease in weight of crossed as compared with selfed kernels, six of which were statistically significant. Preston was the male parent in four of these crosses. The data indicate that Preston exerted a depressing influence upon seed weight when used as the male parent. Several different crosses involving three or less spikes were included in one group upon which no probable error was calculated. A 10% decrease in crossed as compared with selfed kernels was shown by this group, which compares favorably with the 11% average decrease shown by all crossed kernels when compared with all selfed kernels presented in this table. A total of 36 different crosses involving 242 spikes which produced 2,207 selfed and 1,845 crossed kernels was used in obtaining these averages.

TABLE 6.—*Comparison between the average weights of kernels produced by the crossed side and those produced by the selfed side of the same spike, spring wheats, 1929.*

Material	Number of spikes	Average number kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels, with odds
Selfed Bobs	16	9.6	23.6	—2.9 with
Bobs x Penny	16	8.3	20.7	odds 234:1
Selfed Bobs	8	8.9	24.4	—3.3 with
Bobs x Illinois 1	8	6.8	21.1	odds 216:1
Selfed Bobs	4	8.5	25.8	—5.7 with
Bobs x Prelude	4	7.5	20.1	odds 16.2:1
Selfed Bobs	29	8.8	23.9	—5.0 with
Bobs x Preston	29	8.0	18.9	odds 9999:1
Selfed Marquis	16	8.4	20.6	—1.0 with
Marquis x Preston	16	8.1	19.6	odds 7.2:1
Selfed Marquis	7	8.3	23.0	—4.0 with
Marquis x Illinois 1	7	6.0	19.0	odds 11.9:1
Selfed Marquis	6	7.5	29.0	—0.4 with
Marquis x Penny	6	8.0	28.6	odds 6.6:1
Selfed Marquis	4	8.0	23.3	—0.2 with
Marquis x Bobs	4	6.8	23.1	odds 1.7:1
Selfed Penny	7	8.6	24.7	—6.3 with
Penny x Preston	7	5.7	18.4	odds 4999:1
Selfed Penny	6	11.2	24.2	—3.2 with
Penny x Illinois 1	6	6.3	21.0	no odds

TABLE 6.—*Concluded.*

Material	Number of spikes	Average number kernels per spike	Average kernel weight, mgm	Increase or decrease in weight of crossed over selfed kernels, with odds
Selfed Preston	6	10.7	21.2	—0.8 with
Preston x Bobs	6	6.7	20.4	odds 1.5:1
Selfed Preston	6	10.0	25.1	—2.9 with
Preston x Club	6	8.7	22.2	odds 5.1:1
Selfed Preston	32	10.5	23.7	—1.4 with
Preston x Bluestem	32	8.5	22.3	odds 12.7:1
Selfed Preston	7	10.4	20.2	+1.5 with
Preston x Marquis	7	9.1	20.7	odds 1.5:1
Selfed Bluestem	9	6.9	21.9	—2.6 with
Bluestem x Preston	9	7.8	19.3	odds 55.1:1
Selfed Club	18	8.7	22.0	—0.7 with
Club x Illinois 1	18	8.1	21.3	no odds
Selfed Club	9	7.9	19.2	—3.1 with
Club x Preston	9	6.8	16.1	odds 28.0:1
Selfed Club	6	8.0	18.7	—0.2 with
Club x Kota	6	5.8	18.5	odds 2.3:1
Selfed Illinois 1	10	9.8	25.6	—4.5 with
Illinois 1 x Club	10	8.8	21.1	odds 3.2:1
Selfed Illinois 1	5	9.4	21.5	—3.2 with
Illinois 1 x Penny	5	7.4	18.3	odds 7.6:1
All others combined				
Selfed kernels	31	9.1	23.1	—2.3 with
Crossed kernels	31	6.7	20.8	no odds
Averages:				
Selfed kernels	12.1	9.1	23.1	—2.5
Crossed kernels	12.1	7.6	20.6	

Fifty-six different crosses were used in the study of kernel vigor when both crossed and selfed kernels were produced on the same spike. Only 3 of these, involving 19 spikes which produced 148 kernels, showed an increase in weight of crossed over selfed kernels and none of these gave odds indicating statistical significance. Due to the large numbers used, and to the method of comparing crossed with selfed kernels produced on the same spike, it is felt that considerable confidence can be placed in the results obtained. These results reveal no hybrid vigor affecting the weight of the F_1 crossed kernels.

THREE-YEAR AND TWO-YEAR AVERAGES

Since the method of producing crossed and selfed kernels varied from year to year in these experiments, the relative weights of selfed and crossed kernels may have also varied. Only two crosses were compared over a 3-year period for vigor shown by kernel weight. The results obtained from a study of these two crosses are presented in Table 7. Each cross was quite consistent in performance over the 3-year period showing decreases in crossed as compared with selfed kernels, but no statistically significant decrease was shown. For the cross Minnesota Reliable x Nebraska 28 a decrease of 0.3 mgm (1.7%) was shown, while for the reciprocal cross a decrease of 0.5 mgm (2.6%) was shown.

TABLE 7.—*Performance of crosses over a 3-year period, 1927–29, weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent.*

Material	Year	Number of spikes	Ave. No. kernels per spike	Ave. kernel weight, mgm	Increase or decrease of crossed over selfed kernels, with odds
Selfed Minn. Reliable	1927	4	12.3	17.3	
	1928	6	25.3	17.3	
	1929	37	5.4	17.6	
Average		15.7	8.5	17.4	
Minn. Reliable x Nebr. 28	1927	3	8.0	16.1	—1.2
	1928	5	15.2	16.8	—0.9 odds 2.5:1
	1929	37	3.1	17.4	—0.2 odds 7.6:1
Average		15.0	4.8	17.1	—0.3
Selfed Nebr. 28 beardless	1927	6	18.3	15.9	
	1928	6	30.8	19.9	
	1929	26	6.1	20.2	
Average		12.7	11.9	19.0	
Nebr. 28 beardless x Minn. Rel.	1927	4	4.8	14.5	—1.5
	1928	6	13.8	17.3	—2.6 odds 4.6:1
	1929	26	5.9	19.6	—0.6 odds 3.8:1
Average		12.0	7.1	18.5	—0.5

In Table 8 are presented data comparing crossed with selfed kernels produced during two different years. The results for 4 of the 12 crosses show an increase for one year and a decrease for the other. For the cross Indiana Swamp Selection x Ilred the crossed kernels were slightly heavier than the selfed kernels. For the seven remaining crosses the crossed kernels were consistently smaller than the selfed kernels. Odds are presented wherever the numbers are suffi-

ciently large to warrant the application of probable error to the data. For the cross Hardy Northern x Michikof a significant decrease in weight of crossed kernels was obtained in both years. In these experiments Hardy Northern has been consistent in producing decreases in weight of crossed as compared with selfed kernels regardless of the cross involved or the year it was studied. The cross Indiana Swamp Selection 3 x Ilred gave results which indicate a slight degree of hybrid vigor in the crossed kernels. On the whole, the data for both years were fairly consistent and suggest little vigor in F_1 crossed kernels as shown by average kernel weights.

TABLE 8.—*Weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent, over two-year periods.*

Crosses	Year	Number of selfed spikes	Number of crossed spikes	Ave. No. selfed kernels per spike	Ave. No. crossed kernels per spike	Increase or decrease in weight of crossed over selfed kernels, with odds
Ilred x Ind. Swamp Sel.	1927	3	3	14.0	8.0	—1.0
	1928	2	2	28.5	21.5	—0.6
Ind. Swamp Sel. No. 3 x Ilred	1927	5	4	13.0	8.5	+0.1
	1928	6	4	33.2	16.8	+1.5 odds 1.4:1
Nebr. 28 beardless x Red Cross	1927	3	6	16.7	6.2	—1.9
	1928	5	5	20.6	13.4	+1.3 odds 1.2:1
Nebr. 28 x Minturki	1927	6	2	18.3	14.0	—2.9
	1929	8	8	7.4	8.6	—1.0 odds 3.1:1
Ind. Swamp Sel. 3 x Michikof	1928	6	7	33.2	11.0	—2.2 odds 3.0:1
	1929	13	13	7.8	4.2	—3.3 odds 101.0:1
Ind. Swamp Sel. 3 x Wheedling	1928	6	4	33.2	12.7	—1.4 odds 1.4:1
	1929	6	6	7.2	1.2	—0.7 odds 2.1:1
Michikof x Minturki	1928	20	10	25.1	13.0	—2.6 odds 11.5:1
	1929	11	11	4.6	3.8	—1.5 odds 39.1:1
Michikof x Hardy Northern	1928	20	14	25.1	14.5	—3.2 odds 37.4:1
	1929	10	10	3.6	3.5	—1.5 odds 4.0:1
Hardy Northern x Michikof	1928	11	17	28.0	15.9	—4.1 odds 19,230:1
	1929	8	8	6.7	2.8	—2.4 odds 30.6:1
Ind. Swamp Sel. x Wheedling	1928	9	4	31.0	18.3	+4.9 odds 10.3:1
	1929	6	6	6.3	4.7	—3.9 odds 2.1:1
Minturki x Nebraska 28	1928	12	5	24.5	14.5	+0.1 no odds
	1929	4	4	7.7	1.8	—0.3 odds 2.4:1
Minturki x Michikof	1928	12	2	24.5	20.0	—0.1
	1929	17	17	7.6	4.6	—2.2 odds 53.0:1

FREQUENCY OF INCREASES IN WEIGHT OF CROSSED OVER SELFED KERNELS

The instances of increase in crossed over selfed kernels for the 3-year period, 1927–29, are summarized in Table 9. All instances of decrease were omitted from this table. Of the 107 crosses studied, the 18 included in Table 9 showed increases of crossed over selfed kernels, though of these only 2 were significant. Eight of the 18 crosses studied in 1927, including 171 of the 459 crossed kernels produced, gave an increase of crossed over selfed kernels. In 1928, only 7 of the 32 crosses including 421 of the 2,202 crossed kernels

TABLE 9.—*Weight of F_1 crossed kernels compared with weight of selfed kernels, including only those crosses showing crossed kernels to be heavier than selfed kernels, 1927–29.*

Crosses	No. of selfed spikes	No. of crossed spikes	No. of selfed kernels	No. of crossed kernels	Increase in weight of crossed over selfed kernels, mgm, with odds
		1927 Crosses			
Hardy Northern x Nebr. 28 beardless	4	3	58	32	+4.1
Hardy Northern x Mich. Amber	4	1	58	13	+2.9
Minn. Reliable x Mich. Amber	4	2	49	31	+4.2
Mich. Amber x Minturki	8	2	212	19	+0.3
Mich. Amber x Minn. Reliable	8	1	212	12	+1.0
Ind. Swamp Sel. x Ilred	5	4	65	34	+0.1
Nebr. 28 x Michigan Amber	3	1	50	14	+1.6
Minturki x Hardy Northern	7	1	134	16	+0.8
		1928 Crosses			
Ind. Swamp Sel. No. 3 x Ilred	6	4	199	67	+1.5 odds 1.4:1
Minturki x Nebr. 28 beardless	12	5	321	58	+0.1 no odds
Minturki x Wheedling	12	2	321	18	+0.1
Ind. Swamp x Wheedling	9	4	279	73	+4.9 odds 10.3:1
Wheedling x Ilred	9	5	195	75	+2.6 odds 64.8:1
Nebr. 28 x Red Cross	5	5	103	67	+1.3 odds 1.2:1
Hardy Northern x Red Cross	6	8	62	63	+3.8 odds 215.9:1
		1929 Crosses			
Nebraska 28 x Minturki	8	8	59	69	+1.0 odds 3.8:1
Nebraska 28 x Ind. Swamp Sel.	4	4	23	25	+1.0 no odds
Preston x Marquis	7	7	73	64	+1.5 odds 1.5:1

studied gave an increase, and in 1929 only 3 of the 56 crosses including 148 of the 2,558 crossed kernels gave an increase of crossed over selfed kernels. A total of 5,730 crossed kernels was included in this study of hybrid vigor. The methods as well as the large numbers used in these experiments should have revealed significant increases in weight of crossed kernels due to xenia if such increases were very prevalent. In general, it can be stated that little, if any, kernel vigor consequent upon fertilization with foreign pollen has been shown in these experiments.

SIGNIFICANT INCREASES AND DECREASES

In evaluating the differences in the average weights of crossed and selfed kernels, the mathematical significance of these differences should be taken into consideration. Table 10 presents a comparison of crossed with selfed kernels and includes only those crosses which gave significant odds that the difference, whether a decrease or an increase, is not due to chance. Of the 107 crosses studied during the 3-year period, 1927–29, 22 showed significant increases or decreases of crossed as compared with selfed kernels. Only 2 of these 22 crosses, involving 13 spikes, showed increases and these can be readily explained upon the basis of selecting large spikes for crossing and small spikes for selfing. In obtaining these data, 701 spikes were studied. The 20 crosses showing significant decreases in crossed as compared with selfed kernels included 230 spikes which is 34% of the total number of spikes produced. Decreases in the weight of crossed as compared with selfed kernels were much more prevalent than increases. Significant decreases were more than 10 times as prevalent as significant increases.

DISCUSSION

METHODS

According to Swingle and Webber (8), xenia was known and reported as early as 1724. In 1913, Blaringhem (1) reported an instance of xenia resulting from a cross between wheat species. This reported increase in kernel size was found among 16 kernels, produced upon a single spike and compared with a "thin maternal" spike, a "thick maternal" spike, and a "thick paternal" spike taken from the two plants producing the cross. The length, width, and thickness of the kernels were secured and increase in size of the F_1 kernels was determined upon that basis. A study of the data presented shows that the averages of the kernel characters of the four different spikes studied scarcely substantiate a conclusion that the F_1 kernels were larger than selfed kernels of the same plant.

TABLE 10.—*Weight of F_1 crossed kernels compared with weight of selfed kernels of the female parent including only those crosses which show significant odds, 1928 and 1929.*

Crosses	No. of selfed spikes	No. of crossed spikes	Ave. No. selfed kernels per spike	Ave. No. crossed kernels per spike	Increase or decrease in weight of crossed over selfed kernels, with odds
Crossed Kernels Significantly Heavier than Selfed Kernels					
1928 Wheedling x Ilred	9	5	21.7	15.0	+2.6 odds 64.8:1
1928 Hardy Northern x Red Cross	6	8	10.3	7.9	+3.8 odds 215.9:1
Crossed Kernels Significantly Lighter than Selfed Kernels					
1928 Michikof x Hardy Northern	20	14	25.1	14.5	—3.2 odds 37.5:1
1928 Hardy Northern x Ind. Swamp	11	17	28.0	15.3	—4.4 odds 19,230:1
1928 Hardy Northern x Michikof	11	8	28.0	15.9	—4.1 odds 19,230:1
1928 Hardy Northern x Wheedling	11	4	28.0	13.9	—5.7 odds 19,230:1
1928 Hardy Northern x Red Cross	11	3	28.0	12.8	—7.2 odds 19,230:1
1928 Ind. Swamp Sel. x Ilred	9	13	31.0	14.2	—1.9 odds 64.8:1
1928 Wheedling x Ind. Swamp Sel	9	5	21.7	10.5	—3.3 odds 267.1:1
1928 Illinois x Club	11	12	18.9	20.1	—3.5 odds 54.0:1
1928 Garnet x Prelude	11	13	18.9	9.9	—3.5 odds 332.3:1
1928 Prelude x Garnet	23	14	16.0	7.4	—3.1 odds 1350.0:1
1929 Michikof x Minturki	11	11	4.6	3.8	—1.5 odds 39.1:1
1929 Minturki x Michikof	17	17	7.6	4.6	—2.2 odds 53.0:1
1929 Ind. Swamp No. 3 x Michikof	13	13	7.8	4.2	—3.3 odds 101.0:1
1929 Hardy Northern x Michikof	8	8	6.7	2.8	—2.4 odds 30.6:1
1929 Bobs x Penny	16	16	9.6	8.3	—2.9 odds 234:1
1929 Bobs x Illinois 1	8	8	8.9	6.8	—3.3 odds 216:1
1929 Bobs x Preston	29	29	8.8	8.0	—5.0 odds 9999:1
1929 Penny x Preston	7	7	8.6	5.7	—6.3 odds 4999:1
1929 Bluestem x Preston	9	9	6.9	7.8	—2.6 odds 55.1:1
1929 Club x Preston	9	9	7.9	6.8	—3.1 odds 28.0:1

Sax (7), in 1921, weighing individual grains, reported vigor in the F_1 crossed kernels of wheat varieties. He did not, however, use for comparison selfed kernels which were produced in the same way as were the crossed kernels. He emasculated a number of heads and pollinated them with pollen of the same variety. He states, "The number of grains set was too small in most cases, for accurate con-

clusions, so a field selection was made instead." His data show that seven of the nine varietal crosses produced crossed kernels which were significantly heavier than the selected selfed kernels. The crossed kernels of only one cross were significantly smaller than the selfed kernels.

The same year Griffee (4) compared crossed kernels of three variety crosses with incrossed kernels of the female parent. He states, "The varietal crosses in every case showed an increased seed weight as compared with the female parent." However, Little Club X Marquis, both 21-chromosome types, produced crossed kernels which were smaller than the incrossed kernels. The average date of pollination of the material studied was the same or approximately the same for both crossed and incrossed seed.

It has been shown by Engledow (2) that the average weight of kernels produced upon tillers is less than the average weight of kernels produced upon the main spike; the later the tiller, the smaller are the kernels produced thereon. Unconscious selection of large spikes for crossing purposes influences the results when the weight of crossed kernels is compared with that of selfed or incrossed kernels. Even with random sampling excessive variation may cause considerable error. Variation in the time of fertilization also affects the results in an experiment which deals with such small differences in weight as are shown by crossed and selfed kernels. The use of large numbers tends to overcome these errors to some extent. Griffee (4) decreased the error entering into such an experiment by using for comparison material pollinated at about the same time.

The experiments presented in this paper have taken into consideration the date of pollination since "selfed" spikes were prepared at about the same time that "crossed" spikes were prepared. This was not always the case, however, as has been shown under a previous heading.

It is believed that by producing both crossed and selfed kernels on the same spike, as was the case in 1929, the above sources of error were practically eliminated with the exception of the error included because of differences in time of fertilization. The time of application of the pollen can be fairly well controlled, but the time of fertilization cannot be controlled. The "approach" method of crossing allows the natural application of pollen any time over a 4- or 5-day periods An experiment conducted by the writer showed that no fertilization took place when pollen was applied 7 days after emasculation. It is very probable that some florets are not pollinated until a few day. after the state of receptiveness has been reached. In that event

kernels developing from relatively late florets would be smaller than those developing from earlier ones. This would in turn cause crossed kernels to be, as an average, slightly smaller than selfed kernels, since, when kernels are self-pollinated, the pollen is at hand whenever the stigma becomes receptive. This is thought to be the only serious criticism of the method of producing selfed and crossed kernels on the same spike.

SIGNIFICANCE OF RESULTS

A total of 107 crosses was involved in producing the crossed and selfed kernels compared in these experiments. Only 18 of these crosses showed any degree of increase in weight of crossed over selfed kernels. Of these 18 crosses only 2 gave significant odds that such increase was not due to chance. That crossed kernels were significantly smaller than selfed kernels was shown by 20 crosses. Most of this decrease was no doubt due, in some measure at least, to the methods used in crossing. The decrease of 8 to 10% in average weight of crossed kernels compares favorably with that of 5% due to incrossing and suggests a common cause, i. e., the method of crossing and incrossing. The average weight of all selfed kernels was 19.5 mgm, while that of all crossed kernels was 18.0 mgm. This is a difference of about 8% in favor of the selfed kernels. A total of 850 spikes producing 7,527 selfed and 5,730 crossed kernels was used in these comparisons.

SUMMARY

The results on hybrid vigor in kernel weight among wheat crosses reported in this paper were obtained from 107 crosses among 28 lines and varieties of common wheat. These crosses included 7,527 selfed and 5,730 crossed kernels.

When produced on the same spikes as selfed kernels, crossed kernels averaged 8% smaller and when produced on different spikes 10% smaller than selfed kernels. Selfed kernels were, as an average, about 5% larger than "incrossed" kernels, suggesting a slight error due to the method of crossing.

Only 17% of the crosses studied showed some degree of increase; all others showed decreases of crossed as compared with selfed kernels, 22% of which were mathematically significant.

Though the 2-year and 3-year data showed some inconsistencies, a general decrease in weight of crossed as compared with selfed kernels was evident.

In general, the experiments reported in this paper showed no significant increase in kernel size which could be attributed to the phenomenon of xenia.

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EARLY TRIALS AND USE OF REED CANARY GRASS AS A FORAGE PLANT[1]

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The statement that the cultivation of reed canary grass (*Phalaris arundinacea*, L) "began in 1824 in England and in 1850 in Germany," made in 1925 by Piper (9, page 16),[3] and repeated in two recent American articles (2, 12), is incorrect insofar as concerns its history in England. Actually, in that country, this grass received attention very much later than in Sweden and the only early trial appears to have been that of Sinclair, who used the ornamental variety—the ribbon grass of the gardens (*Phalaris arundinacea, picta*, L.) and not the common non-striped grass.

Sinclair's experiments, made on very small plats at Woburn about 1812, were first reported in 1813 in the Appendix to Davy's Elements of Agricultural Chemistry, where he refers to the grass as "*Arundo colorata*. Hort. Kew I. P. 174. Eng. Bot. 402. *Phalaris arundinacea*. Striped leaved reed grass. Nat. of Britain" (3, Append. page XXXVI). His later and fuller account of the same experiment leaves no doubt on the subject. "The superior nutritive powers which this grass possesses recommends it to the notice of occupiers of tenacious clay soils. . . . The striped reed canary grass has not yet been found in a wild state. . . . The common wild variety, which grows by the sides of rivers and standing pools. . . . grows to a greater height than the striped leaved variety and does not appear to be eaten by cattle" (13, page 253). Sinclair's experiment has been dealt with by several later authors, including Wahlberg (16, page 69), Storer (15, page 134), and Werner (17, page 117), as though the common wild variety had been used.

The forage value of the grass appears to have first been referred to by Hesselgren, who in a thesis in 1749 reported a study, carried out under the guidance of Linnaeus, in which he tested the palatability to cattle, horses, sheep, goats, and swine of over 600 species of Swedish plants. To all except the swine, by which it was not eaten, the reed canary grass was found to be one of the most palatable of the many grasses tried (6, page 238). It must have been in quite general use as a forage plant in southern Sweden about the time of

[1]Contribution from Division of Soils, University of Minnesota, St. Paul, Minn. Published with the approval of the director as paper No. 933 of the Journal series of the Minnesota Agricultural Experiment Station. Received for publication September 22, 1930.

[2]Chief.

[3]Reference by number is to "Literature Cited," p. 65.

these trials if Sowerby is correct in attributing to Linneaus a statement that the grass was mown twice a year as fodder in the province of Scania (14, page 13).

Retzius in 1806 stated that in many places in Swedish Lapland this grass was thought to give the heaviest yield and the best quality of forage of all the grasses cut for hay, and suggested that in certain places it would pay to sow the seed (10, page 494). Thirty years later Wahlberg, in his book on Swedish forage crops gave directions for sowing the seed and reported the price at which it could be obtained at Hamburg (16, page 69). As early as 1837, according to Kellgren and Nillson (7, p. 13), experiments with the grass were conducted at the Swedish Agricultural College, a yield of 7 tons per acre being obtained in 1840 on a stiff clay soil.

Werner states that this grass was not cultivated in Germany until very shortly before 1854 (17, page 116), and Langethal, in describing the grass in 1847, made no mention of any attempt to establish meadows of it (8, page 46), although, as mentioned above, Wahlberg 12 years before had stated that the seed could be purchased in Hamburg.

The *New England Farmer* in 1834 and 1835 reported trials of *ribbon grass* by Connecticut and New Hampshire farmers, who observed some plants that had fallen on boggy land beside a brook when thrown out of a garden (1, 5, 11). Later it was increased for forage purposes by transplanting roots. The grass was relished by both cattle and horses and it was thought gave promise of becoming of great value for pasture as well as for hay.

About 20 years later Flint gave considerable attention to the wild reed canary grass, which grew in abundance on the State Farm at Westborough, Mass., and recommended that it be included to the extent of 10% in mixtures to be sown on reclaimed peat lands and on marshy grounds liable to be occasionally over-flowed with fresh water (4, pages 164–165). Samples of the wild grass collected from beside Massachusetts brooks were analyzed in 1876 by Storer, who concluded that it would provide a really useful fodder if mown "when very young—that is to say, three times a year" (15, page 134).

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PERCENTAGE OF LINT IN DISTRIBUTED PLATS OF COTTON VARIETIES[1]

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In a previous paper[3] published in this JOURNAL, the writers show that when 10-pound samples taken from a thoroughly mixed bulk of seed cotton are ginned in a 20-saw experimental gin, the probable error of a single determination is approximately 0.200% of lint. This is equivalent to 2 pounds of lint to the acre if a yield of 1,000 pounds of seed cotton is assumed. It was concluded that one sample will give a sufficiently reliable figure for percentage of lint with which to determine acre yield of lint cotton if the sample is taken from the thoroughly mixed total plat production.

In the 1929 cotton variety test at Chillicothe, a 10-pound sample was ginned from each of four distributed plats of 24 varieties. The percentage of lint of each plat is shown in Table 1. The probable error of a single determination, as computed by Hayes' "deviation from the mean" method,[4] is 0.839% of the mean. Or, assuming 33.3% of lint as a general mean for all varieties, the probable error is 0.279% of lint (33.3% of lint x 0.00839). This is a little higher than the error of 0.200% of lint found when random samples from a mixed bulk of cotton were ginned. The difference of 0.079% of lint, however, is equivalent to only 0.8 pound of lint to the acre if 1,000 pounds again is assumed as the acre yield of seed cotton.

In the previous paper, variation in percentage of lint of successive pickings of a variety was considered. A comparison of Table 2 of that paper and Table 1 given here shows that successive pickings of a variety are much more variable in percentage of lint than are total pickings from distributed plats of the same variety.

Although the yields of the distributed plats of a variety varied considerably (Table 1), percentage of lint was relatively constant from plat to plat. When an experiment is on comparatively uniform land, a percentage of lint figure properly derived from ginning the

[1]Contribution from the Department of Agronomy, Texas Agricultural Experiment Station, and the Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Received for publication September 25, 1930.

[2]Superintendent, Substation No. 12, Chillicothe, Texas, and Assistant Agronomist, Office of Forage Crops and Diseases, U. S. Dept. of Agriculture, respectively.

[3]QUINBY, J. R., and STEPHENS, J. C. The accuracy of cotton lint percentage figures. Jour. Amer. Soc. Agron., 22:157–163. 1930.

[4]HAYES, H. K. Control of soil heterogeneity and use of the probable error concept in plant breeding studies. Minn. Agr. Exp. Sta. Tech. Bul. 30. 1925.

TABLE 1.—*Percentage of lint and acre yield of seed cotton in each of four 1/84-acre plats of 24 cotton varieties at Chillicothe in 1929.*

Variety	Plat 1		Plat 2		Plat 3		Plat 4		Percentage of lint	
	% lint	Acre yield of seed cotton, lbs.	% lint	Acre yield of seed cotton, lbs.	% lint	Acre yield of seed cotton, lbs.	% lint	Acre yield of seed cotton, lbs.	Average of four plats	Extreme difference within variety
Snowflake	26.4	585	26.9	733	27.2	513	27.2	613	26.9	0.8
Delfos	28.3	938	29.4	949	29.2	806	29.4	736	29.1	1.1
Durango	30.0	896	30.9	913	30.3	831	30.6	652	30.5	0.9
Lightning Express	30.0	1,007	30.5	896	30.2	940	30.0	848	30.2	0.5
Acala	30.3	978	30.8	923	31.1	1,003	31.3	821	30.9	1.0
Trice	27.2	934	28.4	1,004	27.7	974	27.3	673	27.7	1.2
Lone Star	35.9	887	36.1	887	35.3	919	36.3	804	35.9	1.0
Lankart	37.2	887	38.3	1,102	37.5	958	38.1	878	37.8	1.1
Rowden	32.8	892	33.4	988	33.1	670	32.3	798	32.9	1.1
Sunshine	31.6	1,151	32.3	1,150	31.3	769	31.9	1,018	31.8	1.0
Cliett's Superior	36.9	1,096	37.8	904	37.3	592	37.5	831	37.4	0.9
Blue Wagon	35.8	1,152	37.3	907	36.6	534	36.6	999	36.6	1.5
Mebane	37.2	1,064	38.4	812	38.1	765	37.3	934	37.8	1.2
New Boykin	33.8	1,247	34.7	824	33.4	848	35.0	1,049	34.2	1.6
Kasch	36.4	968	38.1	657	38.1	717	38.4	953	37.8	2.0
Mebane (4120)	32.2	1,072	32.5	757	32.5	877	32.8	1,140	32.5	0.6
Mebane (804)	30.9	1,094	30.9	942	30.2	948	30.9	1,167	30.7	0.7
Wilson's Clev. Big Boll	31.3	1,043	31.6	915	32.2	845	31.3	1,001	31.6	0.9
Western Wonder	41.9	1,118	41.9	833	42.2	801	42.5	894	42.1	0.6
Half and Half	36.6	999	36.4	789	37.2	1,098	37.5	1,008	36.9	1.1
Cook	34.1	694	24.1	743	34.8	892	34.4	958	34.4	0.7
Bank Account	32.7	944	32.0	810	33.0	745	33.1	874	32.7	1.1
Westex	30.6	1,260	30.6	999	29.7	510	30.3	925	30.3	0.9
Greer-Wichita	28.6	1,126	28.9	795	28.6	600	28.9	790	28.8	0.3

production of a single plat may be applied without substantial increase in error to the replicated plats. Or, when the seed cotton production of a single plat is below 10 pounds, the seed cotton produced on two or more of the distributed plats may be massed and a representative sample drawn.

METHODS OF COUNTING THE NUMBER OF LEGUME BACTERIA IN THE SOIL[1]

G. GORDON POHLMAN[2]

It has been known for many years that certain legume bacteria may live in the soil for a long period of time after the particular legume crop has been grown. However, because of the difficulty of isolating these bacteria directly from the soil or of counting the number present, there is little definite information available along this line.

Beijerinck (4)[3] in 1888 reported the isolation of the organism which he called *Bacillus radicicola* from a large number of soil and water samples. He used a legume extract medium for the isolation and the identification of the organisms was made by means of their colony characteristics on this medium. This was very difficult, however, because of the fact that certain other soil organisms have colony characteristics quite similar to those of the legume bacteria. Two years later Nobbe and his co-workers(11) used a similar method for counting the numbers of Rhizobium in soils on which inoculated legumes had been grown.

These investigators also found that the respective legumes were well inoculated when grown on these soils, but as they did not isolate pure cultures from the colonies appearing on the plates nor test their inoculating power, it is by no means certain that the colonies which they counted contained the legume bacteria.

Gage (6) attempted to isolate Rhizobium from the soil, and although he secured inoculation with some of his cultures, it is doubtful if they were pure.

Greig-Smith (7) reported that the number of legume bacteria in the soil varied from none to 5,500,000 per gram and that the numbers varied directly with the fertility of the soil. He used a medium containing levulose, asparagine, sodium citrate, and potassium citrate and identified by means of the colony characteristics. Then he picked colonies and determined nitrogen fixation in solution as further proof that the organisms were legume bacteria.

[1] Contribution from the Department of Soils, Iowa State College, Ames, Iowa. Received for publication October 15, 1930.

[2] Formerly Research Fellow in Soils at Iowa State College; now Assistant Professor of Agronomy, University of West Virginia, Morgantown, W. Va.

The writer takes this opportunity to thank Dr. P. E. Brown for his helpful suggestions in planning the experimental work and in the preparation of the manuscript, and Dr. R. H. Walker for the help which he has given during the progress of the work.

[3] Reference by number is to "Literature Cited," p. 77.

Vogel and Zipfel (13) reported the successful isolation of certain species of Rhizobium from the soil. They demonstrated that the organisms were legume bacteria by the use of agglutination tests which they considered superior to the ordinary test of inoculation.

Lipman and Fowler (8) reported the isolation of the organisms capable of inoculating *Vicia sicula*. They used a soil extract maltose agar and a synthetic nitrogen-free maltose agar, and secured 44 cultures, 21 of which were capable of infecting the host plant.

Manns (10) reported that it was possible to isolate Rhizobium from the soil by means of a soil extract agar containing calcium carbonate, magnesium carbonate, and kaolin. He asserted (9) that good results might be secured with any medium which was suitable for the growing of Rhizobium. He did not state, however, that the organisms which he isolated were actually tested on the host plant.

Wilson (14) used a modified dilution method for counting the species of Rhizobium in the soil. The dilutions were made in the usual manner but instead of incubating the cultures in test tubes, transfers were made from each dilution into sterile soil. The soil was then incubated for 10 to 14 days, after which time sterilized seeds of a legume from the inoculation group to be tested were planted. The plants were allowed to grow for two to three weeks and were then examined for nodules. The results secured by this method showed that as many as 1,000,000 organisms belonging to a single species may occur in certain soils.

Recently, Allen and Baldwin (1) have used a method for the direct isolation of Rhizobium in which the chemotactic effects of the media were utilized. A sterile tube, sealed at one end, and containing the proper medium, was lowered into a soil suspension. After 12 hours the tube was removed from the suspension and the bacteria plated on brom-thymol-blue yeast mannitol agar. Colonies were then picked and inoculation tests made. The majority of the colonies were found to contain bacteria capable of forming nodules on the roots of legumes.

The use of dyes was recently suggested for the isolation of bacteria from the nodules. Batchelor and Curie (3) used the following dyes successfully: Poirriers blue, alkali blue, nigrosin, orcein, methyl blue, pyrenine, azure 1, and eosin. They isolated organisms from peas, soybeans, cowpeas, alfalfa, and red clover. The dyes were used in concentrations which would stain the contaminating organisms, but leave the legume bacteria unstained.

Anderson (2) showed that certain dyes (crystal violet, brilliant green, and malachite green) have a selective action, and because of

their bacteriostactic effect eliminate some of the common contaminating forms but in the same concentration allow the development of Rhizobium.

Vandecaveye (12) also tested the bacteriostatic effect of some acidic and basic dyes. The basic dyes were more marked in their action than the acidic dyes, the extent of the action depending upon the pH.

Different strains of *Rhizobium japonicum* were found to differ in their tolerance to pararosaniline dyes by Wright and Simington (15). Type A strains were sensitive to concentrations of 1 part of crystal violet in 150,000 parts of medium, whereas type B strains were not affected until the concentration reached 1 part in 25,000.

Burke and Burkey (5) found that the tolerance of Rhizobium toward crystal violet was increased by repeated transfers upon media containing this dye, but this tolerance was soon lost if the organisms were grown on a dye-free medium.

Most of the investigators who attempted to isolate Rhizobium directly from the soil failed to test the ability of organisms isolated to cause nodule formation and hence their results are of little value. Only one (Wilson) suggested a quantitative test to measure the numbers present, and the test which he used was slow and cumbersome. The methods of Lipman and Fowler and of Allen and Baldwin, although suitable for qualitative work, are not adapted to a quantitative study of the legume bacterial population of the soil.

While it is known that the legume bacteria do not remain in the soil indefinitely following the removal of the crop, the actual rate of their disappearance and the conditions affecting the rapidity with which they decrease have never been determined. It is not known whether there are periodic fluctuations in the numbers present in the soil or whether they immediately pass into a logarithmic death phase, the slope of the curve depending upon the soil conditions. Nor are the conditions which are favorable for their continuance in the soil known. If these could be determined it is possible that inoculation, once accomplished, would be unnecessary for it might be practical so to regulate soil conditions that the bacteria would remain alive in the soil for an indefinite period and in sufficient numbers to cause good inoculation.

It is also probable that, if these bacteria are present in the soil in large numbers for a considerable period of time, they may have a marked effect upon the other bacterial activities and may also have some effect in rendering plant food available.

The value of a simple, accurate method for determining the number of symbiotic nitrogen-fixing bacteria in soil as an aid in the solution of the above problems is obvious. The attempts to find such a method are reported here.

EXPERIMENTAL

The first attempts to isolate and count the numbers of legume bacteria were made on soils potted in the greenhouse. The soils were kept fallow and received the following treatments: (a) Check; (b) inoculated with a suspension of *Rhizobium japonicum*; (c) inoculated with a suspension of *Rhizobium japonicum* and limed at rate of 1 ton per acre; and (d) inoculated with a suspension of *Rhizobium japonicum;* limed at rate of 1 ton per acre, and treated with phosphate fertilizer at the rate of 200 pounds per acre.

The inoculation was accomplished by watering the pots with a suspension of the organisms grown on the surface of yeast mannitol agar in petri plates. The soil had been tested for the presence of *Rhizobium meliloti* and *Rhizobium japonicum*, by growing alfalfa and soybean plants. No nodules were produced on either of these legumes.

The usual methods of making dilutions and pouring plates were employed. Five plates were poured from each dilution, using soil extract maltose agar and a synthetic nitrogen-free maltose agar having the same composition as that used by Lipman and Fowler. After three weeks incubation colonies were picked from each medium and, after purification, the organisims isolated were tested for their ability to produce nodules on soybeans, alfalfa, or red clover. In none of the tests were any nodules found after four weeks.

Similar attempts to isolate Rhizobium by means of mannitol agar, yeast mannitol agar, and sucrose agar yielded no colonies which could be positively identified as legume organisms. With the soils tested, a large number of bacteria, actinomyces, and molds developed on the plates and the legume bacteria either failed to grow or developed so slowly that they were masked by these other organisms.

Having failed to isolate or count legume bacteria on nitrogen-free media, it was decided to test media containing dyes, the aim being to utilize the bacteriostatic action of the dyes on other organisms. It was also hoped that some dye might be found which would be taken up by the colonies of legume bacteria, and thus aid in distinguishing them. The dyes selected were crystal violet, acid fuchsin, phloxin red, rosaniline hydrochloride, neutral red, congo red, toluidine blue, malachite green, brilliant green, and thionin.

In order to make the test it was first necessary to determine the maximum tolerance of the species of Rhizobium to each of the dyes. For this purpose, yeast mannitol agar, to which was added varying amounts of the above-mentioned dyes, was used. Approximately 10 cc of the dye agar were poured into petri plates into which 1 cc of a suspension of the legume bacteria had previously been placed. At the end of three weeks incubation the number of colonies developing on each plate was counted. It was often noted that with higher concentrations of certain of the dyes, only a few colonies would appear, the dye apparently being toxic to most of the organisms present. The results of these tests on some strains of *Rhizobium meliloti* and *Rhizobium japonicum* indicated that four of the dyes tested were tolerated in fairly high concentrations by the two species of Rhizobium. These were congo red, phloxin red, acid fuchsin, and rosaniline hydrochloride. The colonies were similar to those on the yeast mannitol agar in all respects except color. The colonies on the congo red agar which had a concentration of 1 part of dye in 1,000 parts of the medium, were slightly reddish, due to the adsorption of the dye. The colonies on the phloxin red agar which had the same concentration of dye were brilliant red, whereas those on rosaniline hydrochloride agar, which had a dye concentration of 1 part in 5,000, were white in the center and reddish on the outer edge of the colonies. The sub-surface colonies were deep red. Colonies on acid fuchsin which had a concentration of 1 part in 1,000 were slightly reddish in color.

In an attempt to isolate the legume bacteria from the soil these four dyes were added to separate portions of yeast mannitol agar in the concentrations given above. The procedure was the same as in the previous tests except that dilutions from a soil known to contain the legume bacteria were used instead of the pure cultures. The examinations made during the course of the incubation period showed that with inoculations from the same dilution of soil there were fewer organisms on the media containing the dyes than on the control medium without dye, indicating that there was some bacteriostatic effect upon the organisms which would develop on yeast mannitol agar. However, it was not possible to identify any of the colonies as Rhizobium. The nitrogen furnished by the yeast extract permitted the growth of many organisms which were not sensitive to the dyes used.

It was next attempted to secure counts by the use of dyes in a nitrogen-free medium. A preliminary test showed that the legume bacteria were more sensitive to these dyes in nitrogen-free media than

in the media containing yeast extract. The tests of dye tolerance were limited to four strains of *Rhizobium japonicum*.[4] The results of these tests appear in Table 1.

There was considerable difference in the dye tolerance of the different organisms tested. Organisms 413 and 416 are type A strains and organisms 414 and 415 are type B strains. It may readily be noted that the tolerance of the type B strains is much greater toward some of the dyes than that of the type A strains. This is in agreement with the data secured by Wright and Simington (15). However, the aim was not to make a systematic study of the dye tolerance of the various strains, but to ascertain the maximum concentration of dye which could be used in the isolation of *Rhizobium japonicum* from the soil. The tolerance of the soybean bacteria appeared to be much greater toward congo red, acid fuchsin, and phloxin red so these dyes were used in a concentration of 1 part of dye to 5,000 parts of medium. Dilutions were again made on a soil known to contain the soybean organisms and plates poured with the dye agar.

TABLE 1.—*Dye tolerance in parts of medium per part of dye of four strains of Rhizobium japonicum on a nitrogen-free medium.*

Dye	Organism			
	413	414	415	416
Rosaniline hydrochloride	50,000*	10,000†	15,000	50,000*
Congo red	4,000–5,000	2,000†	2,000†	4,000–5,000
Acid fuchsin	2,000†	2,000†	2,000†	2,000†
Phloxin red	3,000–5,000	2,000	2,000	3,000–5,000
Thionin	200,000	200,000	200,000	200,000
Neutral red	25,000†	25,000†	25,000†	25,000†
Toluidine blue	50,000*	40,000	40,000	40,000
Crystal violet	750,000	100,000	100,000	750,000
Malachite green	300,000	200,000	100,000†	300,000
Brilliant green	1,000,000*	500,000	500,000	1,000,000*

*Lower concentration not tested. Organisms failed to grow in this concentration.
†Higher concentration not tested.

After incubation for three weeks the plates were examined. None of the plates showed any colonies which could be positively identified as *Rhizobium japonicum*, although a few did resemble the colonies produced by the soybean organisms.

A test similar to Wilson's modified dilution method was also used Sand was used instead of soil and in addition to the nutrient solution 5 cc of a solution containing 10 grams of mannitol per liter were added

[4]These strains were secured through the courtesy of Dr. I. L. Baldwin of the Wisconsin Agricultural Experiment Station.

to serve as a source of energy for the rapid multiplication of the bacteria. The test was first made on a pure culture of *Rhizobium japonicum* and the results compared with the numbers found by the plate method. The figures secured were as follows: Plate method, 466,000,000 bacteria; modified dilution method, 300,000,000 bacteria.

In the dilution method the data were obtained by inoculation into triplicate flasks. The dilution method is not as accurate as the plate method, but the results secured indicate that it may have some value in determining the number of legume bacteria in the soil. The numbers secured by this method will probably be lower than the actual number present because of the possibility of failing to secure inoculation even though there are bacteria present.

A test of the method as used above was also made on a soil which had grown inoculated sweet clover. The results secured by calculating the numbers from the triplicate flasks showed that there were 7,500 sweet clover bacteria per gram of soil. This is a much lower count than those secured by Wilson on soils containing inoculated legumes. It is possible that, due to the competition of other organisms which grew in the sand cultures, inoculation was not secured in all of the dilutions which had initially received one or more of the sweet clover bacteria.

DISCUSSION

The results secured here indicate that it is not possible to isolate and count the numbers of legume bacteria in soils by the use of nitrogen-free media, owing to the many other organisms which develop on such media. The use of dyes in media as an aid in the isolation and counting of the legume bacteria in soils did not give satisfactory results, but the data are insufficient to prove that they can not be used for this purpose. A more detailed study of their bacteriostatic action on soil organisms under varied conditions should be made before conclusions are drawn.

The method of Wilson, or some modification of it, appears to give an approximate count of the numbers of each species of legume bacteria in the soil, but this method requires too much time to be accepted generally.

The results secured in the study of dye tolerance indicated that, although there was little difference in the organisms belonging to the same type within the species, there was a difference in the dye tolerance of the two types tested. This suggests the possibility of using dyes in media for separating various strains within species. However, more tests should be made before any one dye is recommended for use in this separation.

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BOOK REVIEWS

(DER FLACHS ALS FASER- UND OLPFLANZE) FLAX AS A FIBER AND OIL PLANT

By Fr. Tobler, Editor. Berlin: J. Springer. VI + 273 pages, illus. 1928. 19.50 R. M. (about $4.90).

This book is essentially a very complete compilation of the literature on the botany, culture, and diseases of flax. It deals chiefly with flax as a fiber crop and to a less extent as a seed crop. The chapters on botany; morphology of the flax stem; the history of flax cultivation; areas of production; field handling of fiber flax; and the manipulation of flax in separating and preparing the fiber, are written by the editor. A chapter on flax breeding by G. Bredeman; and a chapter on flaxseed, linseed oil, and meal by E. Schilling, are of interest to agronomists. A feature of particular value is the very full treatment of flax diseases, insect pests, and weeds, written by E. Schilling. He reviews very fully the published literature on 26 fungous and bacterial diseases of flax, including wilt, rust, pasmo, and a few less common diseases occurring in the United States. A list of literature occupies nearly 16 pages. This is a book which should be found on the shelves of every agricultural college library. (A. C. D.)

(DER FLACHS) FLAX

By W. Kind, P. Koenig, W. Müller, E. Schilling, and C. Steinbrinck. Berlin: J. Springer. IX + 427 pages, illus. 1930. $13.50.

This is Vol. V, part 1, of *Technologie der Textilfasern*, edited by Dr. R. O. Herzog.

Like Tobler's work, this new book treats of flax principally as a fiber plant. The first part, 48 pages, by C. Steinbrinck, treats of the physics of cellulose fibers in general. The second part, 158 pages, by E. Schilling, treats of the botany of the flax plant, the morphology of the flax stem and the fiber, the culture and diseases of flax, genetics and practical selection, and briefly of the seed, oil, and meal. The third part, 63 pages, by W. Müller, deals with the retting and preparation of the fiber. The fourth part, 30 pages, by W. Kind, treats of bleaching and mercurization of the fiber. The fifth and last part, 108 pages, by P. Koenig, discusses the world production, by countries, of flax and flax fiber. This chapter also deals with the linen industry of the world. A very extensive bibliography of literature follows the second, third, and fifth parts. This volume probably is most valuable to the fiber technologist, although the parts dealing with the morphology, physiology, and botany are very complete. (A. C. D.)

TROPICAL SOIL-FORMING PROCESSES AND THE DEVELOPMENT OF TROPICAL SOILS

With Special Reference to Java and Sumatra

By E. C. J. Mohr. Manila: University of the Philippines Agricultural Experiment Station. 213 pages. $1 plus postage.

This was originally published in Dutch but has been translated into the English by Dr. Robert L. Pendleton, Professor of Soil Technology,

College of Agriculture, University of the Philippines, and published in limited edition in mimeographed form as Experiment Station Contribution No. 655. It consists of 213 pages including an excellent index. The first 52 pages discuss processes of soil formation under tropical conditions. The rest of the publication describes the character of the soils together with a discussion of their formation throughout Java and Sumatra. (C. F. S.)

AGRONOMIC AFFAIRS

MEETING OF THE NEW ENGLAND SECTION

The seventeenth annual meeting of the New England Section of the Society was held at the Hotel Bellevue, Boston, November 28 and 29, 1930. The Friday afternoon session was given over to a consideration of the general topic of fertilizer ratios and was attended by about sixty. At the banquet meeting Dr. Beaumont described conditions as he found them in Russia in 1930. Some 75 attended the Saturday morning session devoted to the general topic of grass varieties, seed production, and fertilizers for golf turf. Twenty-five of those present were New England greenkeepers.

At the business session held Saturday morning a new constitution and by-laws were adopted. It was voted to change the name of the organization from the New England to the Northeastern Section, American Society of Agronomy, and to invite the six states of New York, Pennsylvania, West Virginia, Maryland, New Jersey, and Delaware to join with the New England states in the new organization. Dr. T. E. Odland, Kingston, R. I., Dr. H. B. Sprague, New Brunswick, N. J., and Dr. M. H. Cubbon, Amherst, Mass., were elected President, Vice-president, and Secretary-treasurer, respectively, for 1931. The program follows:

Seventeenth Annual Meeting
New England Section, American Society of Agronomy
Boston, November 28 and 29, 1930

November 28

2 P. M. B. E. Gilbert, Chairman

Fertilizer Ratios

Nitrate Determinations in Soil and Plant as an Aid to Interpretation in Agronomical Data, by J. B. Smith.

Drainage Losses During an Abnormally Dry Year Under Various Nitrogenous Fertilizer Applications, by O. E. Street and H. G. M. Jacobson.

Fertilizer Ratios and Sources of Nitrogen for Potatoes in Arootsock County, by J. A. Chucka.

The High Spots of the Knoxville Lime Conference, by M. F. Morgan.

Report of Fertilizer Ratio Committee, by A. B. Beaumont, *Chairman*.

Banquet at 6:30 P.M.

Russia in 1930, by A. B. Beaumont.

The Russian Viewpoint of Fertilizer Ratios, by J. P. Helyar.

November 29

9:00–10:00 A. M. Business Meeting.

10:00–12:00 A. M. Symposium on Turf Experiments for Lawns and Golf Courses.

1. Strains and Varieties of Golf Grasses for the Northeastern States—classification, adaptation, and disease studies, by L. S. Dickinson.
2. Experiments with Fertilizers and Lime for Lawns and Golf Courses in the Northeastern States, by H. B. Sprague.
3. Experiments in Soil Acidity Control and in Seed Production of Bent Grasses, by T. E. Odland.

NEWS ITEMS

DR. CARLETON R. BALL, formerly Principal Agronomist in charge of the Office of Cereal Crops and Diseases, and for more than 30 years in the service of the U. S. Dept. of Agriculture, went to California early in January to undertake a survey of the relationships of the federal, state, and local (county or city) governments in the numerous and varied agricultural activities of that state. This survey is one, and the first, of a series designed to cover these relationships in all human activities in California. They are conducted by the Bureau of Public Administration of the Department of Political Science of the University of California at Berkeley, with funds provided by the Rockefeller Foundation. The plan is to complete and publish the agricultural survey in 1931.

MANLEY J. CHAMPLIN, Chief of the Department of Field Husbandry in the University of Saskatchewan, at Saskatoon, is pursuing graduate studies in agricultural economics at the University of California during the current academic year.

R. A. FISHER, Chief Statistician, Rothamsted Experiment Station, will give a course of lectures in the first six-weeks session of the 1931 summer school at the Iowa State College. The title and description of the course will be announced later but it is presumed that the lectures will be of special interest to research workers in agronomy and biology.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 FEBRUARY, 1931 NO. 2

HYBRID VIGOR IN WHEAT (*TRITICUM VULGARE*)[1]

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Plant hybridizers of the past observed and reported definite increases in vigor as shown by size and vegetative productiveness of first-generation plants resulting from fertile crosses. This increase in vigor was not confined to crosses within a species, but was shown in interspecific crosses as well. For a review of the early literature upon hybrid vigor reference should be made to Swingle and Webber (28)[3], Jones (17), East and Jones (10), and Roberts (21).

More recently, workers in the field of plant breeding have reported hybrid vigor among both self- and cross-fertilized plants. The results of many careful experiments which have been conducted to ascertain the extent of this vigor make it evident that appreciable vigor resulting from crossing different plants is a general phenomenon. Hybrid vigor has been reported by recent investigators in commonly self-fertilized crop plants, such as tobacco, cowpeas, peas, tomatoes, soybeans, rice, oats, and wheat.

Sax (24), in 1921, using plant height as a criterion, and Griffee (16), using plant height, total culm length, and yield of grain as criteria, reported appreciable increase of F_1 over the parental average, both among varietal and specific crosses of wheat.

In order to test further the extent and degree of vigor shown by F_1 hybrids between different varieties or "pure lines" of wheat, crosses between several pure lines were made during the period 1926–29

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication September 29, 1930.

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[3]Reference by number is to "Literature Cited," p. 104.

using the "approach" method of Rosenquist (22) to insure the production of as large an amount of F_1 crossed seed as possible. By growing and studying relatively large numbers of F_1 individuals it was thought that errors due to very small samples might be avoided.

MATERIALS

SOURCES OF SEED

Most of the lines used in these crosses were obtained from the Plant Breeding Division of the Agronomy Department of the University of Illinois. Of those from other sources Prelude, bearded and beardless types from Nebraska 28, and Bobs were obtained from the Agronomy Department of the University of Nebraska; Preston (Minn. 188) and Bluestem (Minn. 169) were obtained from the Plant Breeding Department of the University of Minnesota; and Penny (C. I. 4993) and Little Club were obtained from the U. S. Dept. of Agriculture Bureau of Plant Industry.

NON-TYPICAL PLANTS IN LINES AND HYBRIDS

Harvesting and threshing were done without the use of machinery in order to eliminate mixtures. Seed to be planted in the yield tests was usually produced under paper bags to insure selfing, but in a few cases seed from uncovered heads was planted to finish the row.

The lines obtained from the University of Illinois Plant Breeding Division, with one exception, bred true each year for all visible characters. This exception was Michikof, Progeny 610, which in 1929 produced 8 brown chaff individuals in a total population of 305. Among the other winter wheat lines only Nebraska 28, both bearded and beardless selections, produced mixtures which amounted to 12 in a population of 141 individuals. Penny (C. I. 4993), when first grown in Nebraska for crossing purposes only, produced 2 durum plants in a population of about 100 plants. All other lines used bred true so far as could be ascertained by observation.

As stated in a previous paper, there were no non-typical plants found in 1927, 0.8% in 1928, and about 1% in 1929. The small amount of error introduced in this manner is of little significance.

METHODS

PRODUCING AND PLANTING THE SEEDS

In order to test the accuracy of the crossing methods, lines differing either in having awns or no awns or in having brown or white chaff were used for each cross. The crosses were made in the greenhouse in the spring of 1926 and the following fall the F_1 crossed seed and the

"selfed" seed of the parents, produced by manipulation similar to crossing and differing only in being self-fertilized instead of cross fertilized, were planted in the screen garden of the Plant Breeding Division of the University of Illinois. The seeds were planted at the usual seeding time in the fall, in well-packed furrows at a uniform depth, spaced 4 inches apart in the rod rows, which were 12 inches apart, and covered uniformly. The parents were grown in rows, one on each side of the row containing the F_1 hybrid plants.

In 1927, the same procedure was followed though some F_1 seed was produced in the field. The plants were grown in the winter wheat nursery of the Agronomy Department of the University of Nebraska and were in rows which were 10 inches apart instead of 12 inches as at Illinois.

Through the lack of greenhouse space in Nebraska the crosses in 1928 had to be made in the field. The crosses were made at times when there was little or no wind. The hybrid and parent seeds were planted exactly as in 1927.

Most of the F_1 hybrid seed was produced in the greenhouse in 1929 though the greater part of the winter wheat crosses was made in a very small completely isolated field. All of the spring wheat crosses were made in the greenhouse.

HARVESTING

When ripe, each plant was cut off at the surface of the ground and placed into a properly labeled paper bag closed at the mouth with a paper clip and left until the plant was air dry before threshing. In 1929, however, all plants, including those spaced 1 inch apart, were pulled. The plants pulled out of any one row (all like plants) were tied into a bundle and the heads well wrapped in paper pending the time (two or three weeks) when further notes were taken and they were threshed. To prevent the breaking-off of culms and serious mixing of plants which were spaced 1 inch apart, the plants were first dug out of the ground with a spade and then separated from the adhering soil. By this method separation into single plants was quite accurate.

THRESHING

The spikes were cut off, weighed, and threshed by passing between two rollers covered with corrugated rubber until all the grain was freed from the glumes. The grain was then winnowed near an electric fan and weighed. In 1928 and 1929, however, another method was used which was found to be superior to the above. All spikes from a single plant were placed in a strong cloth bag which was then pounded

against a hard surface until all kernels had been cleared of their glumes. The bag was then turned inside-out and thoroughly cleaned of any adhering glumes, kernels, or awns. Winnowing was done in the usual manner. This method eliminated danger of mechanical mixture during threshing and was more rapid than any machine used.

INDIVIDUAL PLANT NOTES

At the time when heading began a numbered tag was hung upon each plant. The following notes upon individual plants were taken: (a) Date in pollen, (b) tillers per plant, (c) tillers bearing spikes, (d) plant height, (e) plant weight, (f) grain weight, (g) spike weight, and (h) date ripe. Only the first six characters are discussed in this paper.

NOTES TAKEN IN THE FIELD

The plants were examined every day after heading began. The date in pollen was taken as the date when the first anthers protruded from the flowers of the earliest spike on the plant. This seemed to be a more accurate criterion of maturity than heading date or ripening date as it was more easily observed and more nearly represented the time when maturity (i. e. the reproductive stage) was actually reached. The height of the plant was measured from the ground to the end of the tip spikelet of the tallest culm and did not include the awns.

NOTES TAKEN AFTER HARVESTING

The total number of tillers per plant and the total number of culms producing spikes were carefully counted for each plant. Neither of these criteria includes the main culm; hence, the number of tillers plus one, gives the total number of culms and the number of spikes plus one gives the total number of spikes per plant.

Each plant, minus the roots, was weighed to 0.5 gram upon accurate scales; the spikes were then cut off and weighed on the same scales, also to 0.5 gram. In 1929, the grain, after having been threshed and winnowed, was weighed on the same scales as the spikes, but in 1927 and 1928 the grain was weighed on different scales and to 0.01 gram.

RESULTS

Increase in vigor over that of the parents sometimes shown by hybrid plants may be expressed in many different ways. Those studied and discussed in this paper are as follows: Maturity, including date in pollen and date ripe, number of tillers per plant, number of tillers producing spikes, barren spikes per plant, average plant height in inches, average plant weight in grams, average spike weight in grams, and average grain weight in grams.

The results reported in this paper refer to the parents and F_1 hybrid generation only, since the F_2 was not grown. Twenty-six different crosses were studied during the 3-year period. Only one of these was grown for 3 years, while five were grown over a 2-year period. Yearly data obtained upon the individual crosses did not lend themselves readily to summarizing. As a consequence, the tables reproduced in this paper are not direct summaries but attempts to summarize the trend of the F_1 crosses by comparisons with their parents and with the average of the parents. Anyone further interested in the yearly data can obtain the tables in a thesis on "Hybrid Vigor in Wheat" which is on deposit in the library of the University of Illinois.

The method of presenting the data may unduly influence the conclusions drawn therefrom. In this paper each hybrid is classified into one of three groups, namely, (a) the same as or below the low parent (designated as below the low parent), (b) intermediate, and (c) the same as or above the high parent (designated as above the high parent). This method proved to be the best adapted to the presentation of the data.

WINTERHARDINESS

In the winter of 1926–27 about 25% (111 plants from the 440 seeds planted) failed to survive the winter. Those plants surviving the winter grew in an environment having 329 plants where 440 were expected from the spacing rate used which made an average of 5.4 inches space per plant in each row. This distance, however, was far from uniform, being dependent upon the relative winterhardiness of the different lines and hybrids.

Again, in the winter of 1927–28, when the plants were grown in Nebraska, unfavorable weather conditions caused considerable winterkilling resulting in a survival of only 514 plants where 2,058 seeds were planted. Of the 1,677 plants which established themselves in the fall, only 30.6% survived. The spacing distance therefore actually averaged 16.0 inches per plant in each row in which 4 inches of space between plants were expected. In several rows no plants whatever survived while others were fairly well filled with plants; hence, conditions were very non-uniform so far as numbers of plants per unit area were concerned.

During the winter of 1928–29 weather conditions were not so severe. However, from the 1,960 seeds of winter wheat spaced 4 inches in the row, only 931 plants established themselves in the spring. Some of this loss was undoubtedly due to poor germination as was the case in 1927–28 when 18.5% of the seeds failed in estab-

lishing healthy plants in the fall. These plants, then, occupied a space averaging 9.4 inches between plants in the row.

In order that the effect of the random distribution of this extra space upon yield of grain per plant might be studied, plants having a perfect stand of other plants all around them were compared with those having no other plants nearer than 10 inches in any direction. Eighteen pure lines and F_1 hybrids, producing 91 plants having a perfect stand all around them and 70 plants having no other plants closer than 10 inches, were studied and the data subjected to analysis by Student's method. The average yield of grain per plant of the plants within a perfect stand was 8.0 grams compared with a mean grain yield of 10.9 grams for those having a 10-inch radius free from other plants, with odds of 111:1 that this difference is significant. Plants developing then in an environment practically free from competition produced as an average 2.9 grams (36%) more grain than those under optimum conditions of competition. This 36% increase or decrease in grain weight, due to the greater or lesser amount of space between the growing plants, no doubt caused a degree of error to enter the experiments.

The plants which grew from kernels spaced 1 inch apart in rows 10 inches apart suffered less from winterkilling since 2,668 plants matured from the 4,053 seeds planted. These plants grew with an average of approximately 1.5 inches between plants in the row which, according to Montgomery (23), is fairly comparable to field conditions.

MATURITY

In wheat, the time of maturity may be a very important factor affecting yield or relative vigor. Where drouth is a limiting factor in production, earliness among varieties may be positively correlated with high yielding ability.

East and Jones (10) state that shortening the time of growth seems to be one of the many expressions of hybrid vigor in a plant. If this is true, a knowledge of the inheritance of maturity is desirable. Thompson (29, 30), from a study of the F_2 and F_3 populations of wheat hybrids, concluded that maturity was dependent upon several genes. Most of the F_3 families studied fell between the parents in maturity though some families earlier than the early parents were obtained.

Using Sonora and Turkey for crossing, Bryan and Pressley (3) found the F_1 to be intermediate in time of heading and the F_2 majority to incline toward the late parent. Florell (13) found a fairly good 3:1 ratio of early and late groups, respectively, when studying the F_2 of wheat hybrids. Over one-half of the F_3 population ap-

parently was homozygous for earliness. Clark (4) and later Clark and Hooker (5) using the crosses Hard Federation x Kota and Marquis, respectively, found earliness to be dominant or partially dominant when F_2 and F_3 were compared with the parents in date of heading.

From a study of the F_1, F_2, and F_3 generations of spring wheat crosses growing beside their parents, Stephens (27) found the F_1 to be "intermediate with a tendency toward the early parent," while F_2 and F_3 data "indicate that earliness may be due to the action of a number of independent multiple factors having cumulative effect."

Noll (20) and Garber and Quisenberry (14), working with crosses of oats, found maturity to be dependent upon two or more factors and earliness to be dominant over lateness.

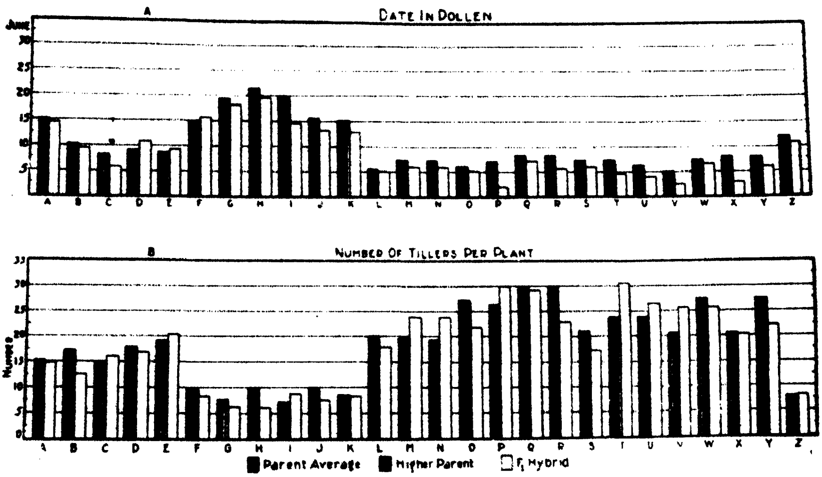

FIG. 1.—A comparison of 26 different hybrids with the parental averages and with the higher parents.

The graphs show about 40% of the hybrids to be as early as the early parent (A) and about 38% to produce more tillers than the higher parent (B). There seems to be a very close negative relationship between the average date in pollen and the average number of tillers per plant.

The data obtained by comparing the F_1 of 26 different crosses with their respective parents, when grown spaced 4 inches apart in the row, are summarized in graph form in Figs. 1 to 3. These graphs include only those characters which were thought to be the most important ones affecting vigor. In these graphs the letters of the alphabet are used to designate different crosses which are listed in Table 1. The first cross, designated A, represents a 3-year average, the next five (B, C, D, E, and F) represent 2-year averages, while all others represent only 1 year's data.

Of the 26 crosses grown, 11 were as early as the early parent, 12 intermediate, and 3 later than the late parent. The general trend seems to be a slight dominance of earliness, since in 42.3% of the crosses the hybrid plants were as early as the early parent, while in only 11.5% were the hybrid plants as late as the late parent.

If early maturity is a criterion of vigor, then all crosses earlier than the early parent should be higher in yield than the higher yielding parent. The total weight of the plant, minus the roots, was used as the criterion of yield since this was thought to be the best measure of the metabolism of the plant. Of the 11 crosses earlier than the early parent, all but one yielded more than the parental average; but of the 3 crosses later than the late parent, 2 yielded more than the high yielding parent, while the other yielded less than the parental average. Four crosses almost as late as the late parent yielded more than the higher parent.

TABLE 1.—*Explanation of symbols used to designate the 26 crosses studied and including the number of plants, the years they were grown, and the number of years' results averaged, with progeny numbers placed in parentheses.*

Symbol	Number of plants			Description
	♀	F_1	♂	
A	104	66	46	Hardy Northern (613) x Michikof (610) 3-year ave., 1927–29.
B	26	25	42	Ind. Swamp Sel. (2) x Red Cross (31), 2-year ave., 1927 and 29.
C	86	25	31	Ilred (11) x Ind. Swamp Sel. 3 (380), 2-year ave., 1928–29.
D	46	35	33	Minturki (611) x Nebr. 28 beardless (752), 2-year ave., 1928–29.
E	35	15	54	Nebr. 28 beardless (752) x Minn. Reliable (614), 2-year ave., 1928–29.
F	53	63	45	Ilred (1) x Ind. Swamp Sel. (2), 2-year ave., 1927–28.
G	32	24	34	Minn. Reliable (614) x Michigan Amber (615), 1927.
H	49	49	45	Hardy Northern (613) x Michigan Amber (615), 1927.
I	22	16	45	Minturki (611) x Michigan Amber (615), 1927.
J	27	13	15	Minturki (611) x Hardy Northern (613), 1928.
K	30	22	20	Hardy Northern (613) x Nebraska 28 beardless (752), 1928.
L	27	20	31	Indiana Swamp Sel. 3 (380) x Michikof (610), 1929.
M	23	27	31	Wisconsin 18 (362) x Michikof (610), 1929.
N	23	27	13	Wisconsin 18 (362) x Nebr. 28 beardless (752), 1929.
O	19	25	19	Michikof (610) x Minturki (611), 1929.
P	17	26	16	Ind. Swamp Sel. (2) x Wheedling (31), 1929.
Q	24	16	16	Hardy Northern (613) x Wheedling (3), 1929.
R	24	22	26	Hardy Northern (613) x Ind. Swamp Sel. 3 (380) 1929.
S	26	13	26	Ind. Swamp Sel. 3 (380) x Wheedling (3), 1929.
T	26	28	23	Wheedling (3) x Ilred (1), 1929.
U	21	8	23	Red Cross (31) x Ilred (1), 1929.
V	21	16	19	Red Cross (31) x Nebr. 28 bearded (751), 1929.
W	35	21	19	Minn. Reliable (614) x Nebr. 28 bearded (751), 1929.
X	7	14	16	Hardy Northern (613) x Ilred (1), 1929.
Y	33	12	38	Hardy Northern (613) x Red Cross (31), 1929.
Z	22	43	36	Garnet x Prelude, 1929.

Were it not for the performance of six relatively late crosses there would be a very close relationship between earliness and high yielding ability. The fact that Nebraska 28 was involved as one parent in all six of these crosses is significant, especially when it is found that every cross containing Nebraska 28 as one parent was relatively late and high yielding.

In these crosses there seems to be a partial dominance of lateness without any correlation whatever with low vigor, since the hybrids were more vigorous than the more vigorous parents. In most other crosses not including Nebraska 28 as a parent, earliness was slightly dominant and early hybrids were quite vigorous while late hybrids were non-vigorous, a condition found also by other investigators. It seems from these data that pure lines may carry entirely different factors for maturity, one set showing earliness to be partially dominant; another, as in Nebraska 28, showing lateness to be completely or partially dominant though kept from expression in the lines involved, possibly by an inhibitor. It is significant that the lines crossed with Nebraska 28, and therefore producing late F_1 hybrids, produced early or intermediate hybrids in every other combination. Disregarding the effect of Nebraska 28 upon earliness and yield, it is evident that relatively early F_1 hybrids were likewise high yielding, thus indicating a degree of hybrid vigor. In these experiments, then, earliness was found to be a fair criterion of vigor.

AVERAGE NUMBER OF TILLERS PER PLANT

When considerable space is available for the use of the growing plant, the ability to tiller profusely should be a good criterion of yield and consequently of hybrid vigor. Grantham (15) has found that plants having a large number of tillers produce more spikes, larger spikes, and more grain per plant than those with few or no tillers. He also states that tillering is a distinct character of the wheat variety. It should then be inherited and Garber and Quisenberry (14), working with oat crosses, found that, based on the F_2, a high number of tillers probably behaves as a dominant character in inheritance. If the ability to tiller profusely is highly correlated with yield, then F_1 populations inheriting that ability as a dominant character should show vigor in total plant weight as well as yield of grain and other characters.

The data presented in Fig. 1B show that 11 (42.3%) of the 26 crosses tillered more profusely than the higher parent, 12 (46.1%) were intermediate, and 3 (11.5%) poorer than the low parent in tillering ability. These data indicate high tillering ability to be

partially dominant to low ability, which agrees with the results found in oats by Garber and Quisenberry. As a partially dominant character, high tillering ability should indicate hybrid vigor. In each cross, when the number of tillers per plant was greater than the parental average, the average weight per plant was also higher than the parental average. Conversely, F_1 hybrids tillering less than the low tillering parent were about the same as the low parent in plant weight. This shows a very close relationship between the average number of tillers per plant and the average weight per plant and indicates that tillering ability was a good criterion of hybrid vigor under the conditions of the experiment. Some degree of vigor was shown by about 42% of the crosses.

NUMBER OF TILLERS PRODUCING SPIKES

The number of tillers producing spikes should be closely related to the average number of tillers per plant and even more closely related to plant yield than was the average number of tillers per plant. Engledow (12), reporting data on only those tillers producing spikes, showed that an increase in the average number of tillers per plant was accompanied by a corresponding increase in the average size of the main spike; in the average size of the first, second, third, etc., tillers; as well as in the average size of the whole plant.

For this character, 14, or 53.8%, of the crosses were better than the higher parent; 7, or 26.9%, were intermediate; and 5, or 19.2%, were poorer than the low parent (Fig. 3A). These data show that a high number of tillers bearing spikes is inherited as a partially dominant character. If now a high number of spikes is closely related to plant yield, this character can be classed as a criterion of hybrid vigor among the crosses involved. Of the 14 crosses producing more spikes than the high parent, all were higher in plant yield than the parental average and all but one were higher in yield than the high parent. One of the five crosses producing fewer spikes than the low parent was higher in plant yield; all others were below the parental average and one below the low parent. All hybrids intermediate in number of spikes per plant were also approximately intermediate in plant yield. A very close relationship evidently exists between number of spikes per plant and plant yield, showing that the number of spikes is a good criterion of plant yield and consequently of hybrid vigor. About 54% of the crosses showed some degree of hybrid vigor as measured by this criterion.

AVERAGE PLANT HEIGHT IN INCHES

Plant height is a character which is easily determined and this fact probably explains why it has been used so often as a measure of hybrid vigor. Sax (24) compared F_1 hybrid plants of wheat collectively with the average of all parents. He found the F_1 plants to be about 8 cm taller than the average of the parents. He states, "The F_1 plants of both the fertile and partially sterile F_1 hybrids are taller than the parent plants."

Griffee (16), working with both varietal and species crosses of wheat, reported upon height and total culm length of F_1 plants as compared with the parents. He says, "In the F_1 generation some of the hybrids exceeded the parental average in height of tallest culm, and in total culm length, others showed a decrease." Four of the 17 crosses reported by Griffee were shorter than the short parent and 9 were taller than the tall parent.

Dietz (8), working with oats from 1919 to 1923, reported striking cases of hybrid vigor among five different crosses. In only one of these crosses, however, was the F_1 generation taller than the taller parent, the other four crosses being intermediate.

Results quite similar to those reported by Griffee were obtained in this study, except that in no cross was the F_1 as short as the shorter parent. In Fig. 3B the hybrids are compared in height with the higher parent and the parental average. No crosses were as short as the short parent, 7 (26.9%) were intermediate, and 19 (73.1%) were taller than the tall parent. This partial dominance of tall over short plants may be an expression of hybrid vigor.

Plant height has been used by many investigators as the main basis, if not the sole basis, of the measure of vigor. Biffen (1) mentions plant height only when speaking of vigor. East and Hayes (9), studying vigor in a tobacco cross, used plant height as a criterion of vigor. Conner and Karper (7), working with sorghums, used height as a measure of vigor. Sax (24) interpreted vigor in wheat solely upon the basis of plant height. Collins (6), referring possibly to hybrids of maize, says, "Height is probably the most satisfactory character to use as a measure of heterosis."

Taking plant height alone as a criterion of hybrid vigor, as some investigators have done, and disregarding the probable error, one would conclude that 73% of the crosses reported in this paper showed hybrid vigor. Biffen (2), however, reports a "violent cross" between Rivet and Red Fife which "produces stems over 6 feet high but apart from this there are no signs of vigor." The aforementioned oat crosses reported by Dietz showed no vigor in plant height, except in one case,

though all yielded much more than either parent. Two of the 8 crosses whose grain yield was obtained by Griffee were shorter than the short parent yet yielded more grain than the parental averages. These are a few examples which show that vigor as measured by plant height is not always accompanied with hybrid vigor in other characters.

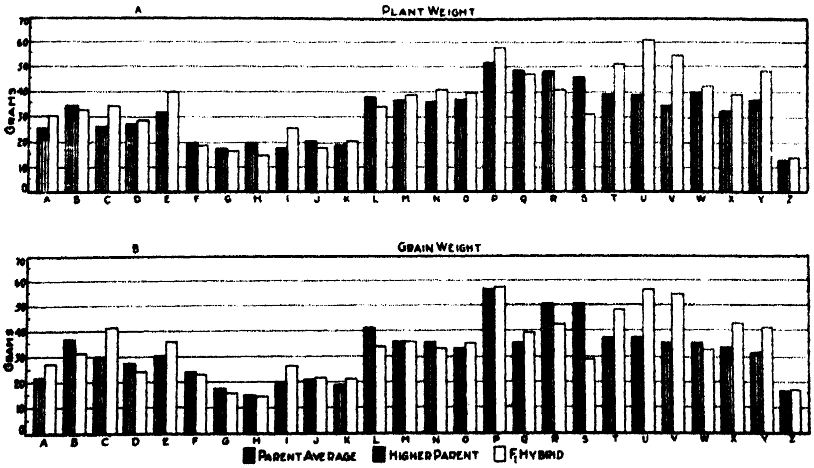

FIG. 2.—A comparison of 26 different hybrids with the parental averages and with the higher parents.

The average plant weight and the average grain weight per plant are shown in A and B, respectively. About 60% of the hybrids are better than the higher parent in both characters. The graphs show a close relationship between plant and grain weights.

In the experiments reported in this paper tall hybrids were not always high in plant yield. Three of the 19 crosses which were taller than the tall parent yielded less than the parental average and two of these yielded less than the low parent. One cross shorter than the parental average yielded more than the high parent. On the whole, however, plant height was a fair criterion of vigor, since 14 of the 19 crosses taller than the tall parent were also higher in plant yield than the higher parent.

AVERAGE PLANT WEIGHT IN GRAMS

It is the opinion of the writer that the air-dry weight of the plant, minus its roots, more nearly represents the actual vigor of a plant than any other character, in spite of the fact that the probable error shows it to be the most variable character studied.

Fig. 2A shows the results obtained when studying this character among 26 crosses and their parents. Three crosses (11.5%) weighed

less than the low parent, 6 (23.0%) were intermediate, and 17 (65.4%) weighed more than the heavier parent. Hybrid vigor may have been shown in some degree by about 65% of the crosses studied, but the opposite of vigor, i. e., a decrease in plant weight, was shown by about 12% of the crosses. The significance of the increases and decreases reported here will be shown later. The fact that high plant weight acts as a partial dominant over low plant weight indicates, in itself, a certain amount of hybrid vigor.

AVERAGE GRAIN WEIGHT PER PLANT IN GRAMS

The average grain weight per plant should be a fairly reliable character for use in determining hybrid vigor. In some years at least it is more subject to environmental conditions than is plant height or plant weight since the grains are often developing just at the period in the life cycle of the wheat plant when soil and climatic conditions are less favorable for the best development, due to drouth and excessive heat. Under such conditions a few days difference in maturity make the difference between a high and much lower yield of grain.

Several investigators have used grain weight as one of the criteria of vigor, some laying the most stress upon this character. Griffee (16), Sax (24), and Dietz (8) have emphasized grain yield in their data, Sax and Dietz using only plant height in conjunction with grain yield to measure vigor. Jones (18), working with rice, used grain weight as one of the most important criteria of the hybrid vigor which he reported. He says, "probably the best indicator of hybrid vigor is the yield (of grain) per plant."

In 14 (53.8%) of the 26 crosses (Fig. 2B), the grain yield was higher than that of the high parent, while 7 (26.9%) were intermediate, and 5 (19.2%) were lower in yield than the low parent. This shows a partial dominance of high over low grain yield. Comparing the grain weight data with those given for plant weight, we find the results to be fairly consistent except in one cross where the hybrid produced more total dry matter than the high parent but yielded less grain than the low parent. Some degree of hybrid vigor was indicated by about 54% of the crosses when grain weight was taken as the criterion.

COMPARISON OF THE DIFFERENT CHARACTERS

A study of Figs. 1A to 3B, as a whole, shows some interesting relationships. The character date in pollen shows a very close negative relationship with number of tillers per plant, late maturity being correlated with few tillers. Since there seems to be a close

relationship between number of tillers, number of tillers bearing spikes, plant weight, and grain weight, the date in pollen shows approximately the same type of relationship to all of these characters. Plant height, however, seems to be only slightly correlated with tillering and plant and grain weights. We would expect, then, only a slight relationship between plant height and date in pollen, which seems to be true in this case. In general, wheat plants tend to reach a certain plant height regardless of their degree of maturity or the extent of their metabolism as measured by weight and tillering.

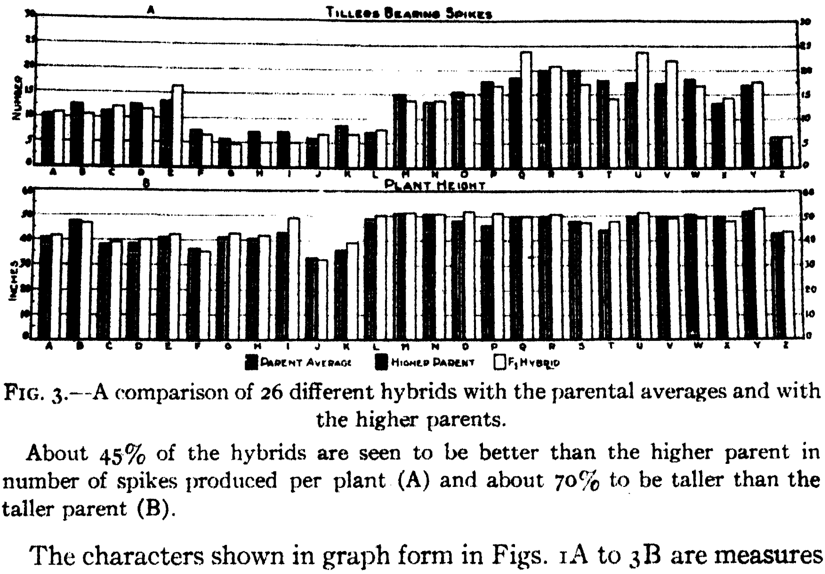

FIG. 3.—A comparison of 26 different hybrids with the parental averages and with the higher parents.

About 45% of the hybrids are seen to be better than the higher parent in number of spikes produced per plant (A) and about 70% to be taller than the taller parent (B).

The characters shown in graph form in Figs. 1A to 3B are measures of hybrid vigor. If each character for vigor is examined separately, it will be found that 69% of the crosses indicate some degree of vigor by being earlier than the parental average, 96% by being taller, 69% by producing more tillers, 69% by producing more spikes, 77% by producing more total weight, and 73% by producing more grain than the parental average. Twelve of the 26 crosses were consistently better and earlier and 4 better but later in every character than the parental average. One cross was consistently better but shorter than the parental average. Two crosses were consistently poorer though taller and later, while two were poorer though taller and earlier than the parental average.

When the hybrids were compared with the parental average, 46% showed exactly consistent performance, 27% were inconsistent for one character only, and 8% were inconsistent for two characters, namely, maturity and height. Only five crosses (19%) were consistently more vigorous and earlier than the superior and

earlier parent, while four (15%) were more vigorous than the superior parent though intermediate to late in maturity. Those crosses consistently more vigorous than the superior parent, whether early or late, undoubtedly showed some degree of heterosis.

Table 2.—*Mathematical significance of the differences found, including only those cases in which there is a significant increase or decrease of the character studied over the parental average (A) or over the higher parent (H).**

Cross	Tillers per plant	Tillers bearing spikes	Plant height, inches	Plant weight, grams	Spike weight, grams	Grain weight, grams
			1927 Results			
Minn. Reliable x Mich. Amber			A+			
Minturki x Mich. Amber	A+	A+	A+H+	A+H+	A+H+	A+
Hardy Northern x Michikof	H—	H—	A+	H—	H—	H—
			1928 Results			
Nebr. 28 x Minn. Reliable	A+	A+	A+	A+		
Hardy Northern x Nebr. 28		A+	A+H+	A+		
Hardy Northern x Michikof			A+			
			1929 Results			
Ilred x Ind. Swamp Sel.				A+	A+	A+
Wisconsin 18 x Nebr. 28			A+			
Michikof x Hardy Northern				A+	A+	A+
Minturki x Nebr. 28			A+			
Michikof x Minturki			A+H+			
Ind. Swamp Sel. x Red Cross	H—					
Ind. Swamp Sel. x Wheedling		A+	A+H+	A+	A+	A+
Hardy Northern x Ind. Swamp			A+			
Wheedling x Ilred	A+	A+	A+H+	A+	A+	A+
Red Cross x Ilred			A+H+			
Red Cross x Nebr. 28 bd.			A+H+	A+H+	A+	A+H+
Minn. Reliable x Nebr. 28 bd			A+			
Minn. Reliable x Nebr. 28			A+			
Hardy Northern x Ilred				A+H+		
Hardy Northern x Red Cross			A+			
Michikof x Hardy Northern			A+		A+	A+
Garnet x Prelude			A+			

*A+ is above and A— is below the parental average; H+ is above and H—is below the higher parent.

SIGNIFICANT DIFFERENCES FOUND

Since hybrid vigor was shown by some of the crosses, the mathematical significance of the data revealing such vigor, as well as the opposite of vigor, should be of interest. Table 2 presents only the crosses showing mathematically significant differences between the hybrid and the parental average and between the hybrid and the higher parent. By including the data of more than one year 35 instead of 26 crosses were used in compiling this table.

Twenty-three of the 35 crosses showed significant increases or decreases in one or more characters when compared with their parents. For all characters and all crosses, only 68 of a possible 156 differences were significant. Of these, 62 (40%) were above the parental average (A + in the table) and 12 (8%) above the higher parent (H + in the table). There were no decreases below the parental average which were significant.

For plant weight, only three crosses were significantly heavier than the heavier parent. The height of the plants showed the most cases of significance, seven crosses being taller than the taller parent. This character showed twice as many instances of significance as any other, which was probably due to its low variability as well as its response to crossing which in every case but one was positive. Plant weight, spike weight, and grain weight were next in frequency in the order mentioned. Certain crosses showed that hybrid vigor may be present but not expressed as plant height, while others showed that height may be the only character showing heterosis.

Only two of the crosses included in Table 1, i. e., Minturki x Michigan Amber and Red Cross x Nebraska 28 bearded, showed consistent significant increases above the higher parent, though eight showed significant increases above the parental average when weights and height were considered. Hybrids showing increases above the higher parent probably obtain some dominant, or partially dominant, growth factors from each parent. When these meet in the F_1 vigor above that of either parent is shown.

It can be seen from Table 2 that the number of instances of hybrid vigor which are mathematically significant is relatively small. Hybrid vigor may be shown, however, by such small differences that they do not appreciably exceed those of place variation and, as a consequence, mathematical significance cannot be obtained except by very large numbers and replication over a period of years. The very fact that the F_1 exceeded the parental average and even the higher parent in a large percentage of the cases is in itself of significance as an indication of the prevalence of heterosis.

DECREASES IN VIGOR

Much has been written regarding the phenomenon of hybrid vigor and fairly adequate theories have been formulated to explain it. East and Jones (10), as well as Jones (17), have given a good discussion of the whole subject of heterosis and the theories for its explanation. Crossing pure lines of wheat does not, however, always result in F_1 hybrids intermediate between the parents or showing some degree of heterosis, but sometimes results in hybrids which are inferior to the low parent in one or more characters. The hybrid was lower than the parental average in 14% of the cases and lower than the low parent in 6% of the cases when, among the 26 different crosses studied, each character was taken individually. The fact that crossing may have an injurious as well as a beneficial effect should not be overlooked.

Shull (25) says, "In the breeding of tobacco it is now well known that cross pollination within the limits of a single strain produces inferior offspring and only self-fertilization gives offspring of the highest degree of vigor, though hybrids between distinct strains of tobacco often display a vigor superior to that of either parental strain." Griffee (16) reported a cross between two pure lines of *vulgare* wheat which produced F_1 lower than the low parent in total culm length. One cross between different species was lower and one as low as the low parent in total culm length.

Decreases in F_1 below the low parent, like those mentioned above, are not readily explained by the commonly accepted theories for heterosis. Since the opposite of vigor was shown it would seem logical to assume incompletely dominant, injurious growth factors (in the same way that dominant favorable growth factors are assumed to increase vigor) as decreasing vigor when they meet in the F_1 individual. Shull (26) anticipated something of this nature when he commented upon vigor in connection with the "heterozygosis" theory thus, "I do not believe that this correlation is perfect, of course, but approximate, as it is readily conceivable that even though the general principle should be correct, heterozygosis in some elements may be without effect upon vigor, or even depressing." The assumption that two or three such dominant or incompletely dominant factors which depress vigor are present among certain pure lines of common wheat will explain the frequency of occurrence of decreases in the F_1 below the parental average and below the low parent, such as were found in these experiments.

TABLE 3.—*Comparison of F_1 hybrids with their parents, spaced 1 inch apart, in the row, 1929.*

Crosses	Total number plants	Space between plants, inches	Tillers per plant	Tillers bearing spikes	Plant weight, grams	Grain weight, grams
Michikof Prog. 610	229	1.7	6.7	4.0	10.3	2.5
F_1 Michikof x Hardy Northern	219	1.8	7.8	4.9	13.1	2.9
Hardy Northern Prog. 613	250	1.6	8.6	5.0	12.8	2.5
Ilred Prog. 1	136	1.5	7.9	4.4	9.7	2.5
F_1 Ilred x Ind. Swamp Sel	132	1.5	8.7	5.4	13.4	3.7
Ind. Swamp Sel. Prog. 2	133	1.5	7.2	4.5	10.1	2.9
Ilred Prog. 1	15	1.7	9.0	5.3	10.0	2.6
F_1 Ilred x Wheedling	15	1.7	10.4	6.4	14.8	3.9
Wheedling Prog. 3	19	1.4	5.8	2.8	5.9	1.4
Hardy Northern Prog. 613	38	2.3	9.0	5.0	13.0	2.8
F_1 Hardy Northern x Wheedling	36	2.4	11.7	5.6	12.5	2.6
Wheedling Prog. 3	29	3.0	8.7	5.0	7.9	1.8
Ind. Swamp Sel. Prog. 2	16	2.6	8.3	6.1	14.4	4.1
F_1 Ind. Swamp Sel. x Wheedling	28	1.5	10.1	6.8	16.5	4.5
Wheedling Prog. 3	18	2.3	10.9	6.3	11.5	2.8
Wisconsin 18 Prog. 362	68	1.4	8.3	4.8	13.2	3.1
F_1 Wis. 18 x Michikof	58	1.7	8.2	5.2	13.7	3.1
Michikof Prog. 610	51	1.9	7.5	5.1	13.8	3.5
Michikof Prog. 610	59	2.0	8.5	6.2	15.3	4.1
F_1 Michikof x Minturki	57	2.1	9.0	6.2	15.9	3.7
Minturki Prog. 611	74	1.6	10.5	7.0	16.3	4.4
Minn. Reliable Prog. 614	54	1.9	8.6	4.6	11.7	2.1
F_1 Minn. Reliable x Nebr. 28	36	2.8	7,6	4.5	11.0	1.8
Nebr. 28 beardless Prog. 752	53	1.9	6.8	6.9	9.6	1.3
Red Cross Prog. 31	35	1.7	5.5	2.7	9.7	2.0
F_1 Red Cross x Nebr. 28 bd.	36	1.6	7.3	4.6	13.9	2.5
Nebr. 28 bearded Prog. 751	23	2.5	6.9	4.1	5.9	0.8
Ilred Prog. 1	25	1.5	9.0	5.2	12.6	3.3
F_1 Ilred x Ind. Swamp Sel	30	1.2	9.8	5.3	11.4	2.7
Ind. Swamp Sel. 3 Prog. 380	16	2.3	11.0	6.7	14.7	3.8

TABLE 3—*Continued.*

Crosses	Total number plants	Space between plants, inches	Tillers per plant	Tillers bearing spikes	Plant weight, grams	Grain weight, grams
Michikof Prog. 610...	30	1.7	11.0	5.9	15.7	3.8
F_1 Michikof x Ind. Swamp Sel.........	39	1.3	7.9	5.0	11.9	3.0
Ind. Swamp Sel. 3 Prog. 380.........	39	1.3	8.5	3.5	8.7	2.1
Wheedling Prog. 3....	10	2.6	9.7	5.6	8.7	1.2
F_1 Wheedling x Ind. Swamp Sel.........	19	1.4	8.5	6.2	12.7	1.5
Indiana Swamp Sel. 3 Prog. 380..........	21	1.2	8.3	3.6	9.7	2.3
Hardy Northern Prog. 613...............	17	1.9	10.7	7.4	19.1	4.2
F_1 Hardy Northern x Ind. Swamp.......	17	1.9	8.7	6.1	17.3	5.5
Ind. Swamp Sel. 3 Prog. 380..........	19	1.7	5.8	4.3	9.4	2.7
Garnet...............	162	1.3	5.0	3.9	9.1	2.6
Garnet x Prelude.....	163	1.3	2.9	1.9	6.2	1.9
Prelude.............	144	1.5	3.2	2.8	6.3	2.0

STUDY OF HYBRIDS AND PARENTS UNDER CONDITIONS OF CLOSE SPACING

The fact that a hybrid may show heterosis when growing under conditions which allow ample space for development may not mean that it will be fully as vigorous when grown under conditions more nearly like those under which it receives its final test. Engledow (11) found that varieties behaved quite differently under different spacing conditions, showing changes in ranking with thick and thin planting.

In order to test the relative yields of hybrids and parents under conditions more nearly simulating those usually found in the field, the remainder of the F_1 seeds of a cross, after planting a rod row spaced 4 inches apart in the row, was planted in other rod rows but spaced 1 inch apart in the row. The parents were treated in exactly the same way as the hybrid which was grown with one parent on each side. Montgomery (19) found wheat spaced 1 inch apart to yield nearly as much as wheat spaced ½ inch apart in the row which is about the rate of planting used in most variety tests of wheat. The hybrids and parent plants when harvested were found to be, on an average, 1½ inches apart in the row which is a survival of about 8 plants per foot (Table 3). Casual observation revealed no evident difference in numbers of plants from drilled material growing in the adjoining plats.

A comparison of crosses grown under 1-inch and 4-inch spacing conditions (Table 3 and Figs. 1A to 3B) shows fairly consistent data. Five crosses spaced 1 inch apart included a large proportion of the F_1 individuals grown. For the cross Michikof x Hardy Northern, 219 F_1 plants were harvested. More than two rod rows were planted to this F_1. The cross Ilred x Indiana Swamp Sel. included 132 hybrid plants; Wisconsin 18 x Michikof, 58 hybrids; Michikof x Minturki, 57 hybrids; and Garnet x Prelude, 163 hybrids. These crosses, because of their relatively large number of plants, will be compared more fully with the same crosses spaced 4 inches apart.

The cross Michikof x Hardy Northern was slightly higher than the parental average in plant and grain weight under each spacing, but spaced 1 inch the hybrid was intermediate in tillering ability, while it was superior to the higher parent when spaced 4 inches. A rather significant result was the fact that in neither total plant weight nor in total grain yield did the hybrid exceed the higher parent, rather it was intermediate when spaced 1 inch in the row. This may be due to the fact that there were 31 (12%) more plants produced by the better parent than by the hybrid. The average yield per plant was in favor of the hybrid which may indicate some hybrid vigor. To be of economic value, however, hybrid vigor must be much more pronounced than was indicated by this cross.

The indication of hybrid vigor given by the cross Ilred x Indiana Swamp when spaced 4 inches apart in the row was partially substantiated by the yield of almost a rod row of the same cross which was spaced 1 inch apart in the row. The total yield of straw and of grain, as well as the average production per plant, was considerably above that of the higher parent. This cross holds some promise if selection within the progeny can isolate pure high-yielding types.

In another cross, Wisconsin 18 x Michikof, the hybrid was about equal to the better parent in each character studied and was consistent for each degree of spacing. The cross Michikof x Minturki was not so consistent in performance though only slight differences were noticeable. With the 4-inch spacing the hybrid was intermediate in tillering and better than the high parent in yielding ability, but with the 1-inch spacing it was intermediate in tillering and plant weight and inferior to the low parent in grain yield.

The spring wheat cross Garnet x Prelude was slightly higher than the high parent when spaced 4 inches, but it was intermediate or below the low parent for all characters when spaced 1 inch apart in the row.

TABLE 4.—*Comparison of F_1 hybrids with the parental average, 4-inch vs. 1-inch spacing, with the average of the parents as 100%, 1929.*

F_1 hybrids	Spacing distance, inches	Total number plants	Tillers per plant	Tillers bearing spikes	Plant weight, grams	Grain weight, grams
Michikof x Hardy Northern Progenies 610 x 613.						
610 x 613	4	23	130	132	157	154
610 x 613	1	219	102	107	114	115
Ilred x Indiana Swamp Sel. 3 Progenies 1 x 380.						
1 x 380	4	21	117	115	138	147
1 x 380	1	132	112	113	122	124
Ilred x Wheedling. Progenies 1 x 3.						
1 x 3	4	28	142	149	167	174
1 x 3	1	15	136	147	186	193
Hardy Northern x Wheedling, Progenies 613 x 3.						
613 x 3	4	16	122	130	135	141
613 x 3	1	36	129	110	119	111
Indiana Swamp Sel. x Wheedling. Progenies 2 x 3.						
2 x 3	4	26	135	154	160	151
2 x 3	1	28	104	109	128	129
Wisconsin 18 x Michikof. Progenies 362 x 610.						
362 x 610	4	27	106	108	107	103
362 x 610	1	58	104	103	101	95
Michikof x Minturki. Progenies 610 x 611.						
610 x 611	4	25	102	116	121	124
610 x 611	1	57	95	94	101	87
Minn. Reliable x Nebr. 28 Beardless. Progenies 614 x 752.						
614 x 752	4	7	99	100	132	121
614 x 752	1	36	99	82	104	108
Red Cross x Nebr. 28 Bearded. Progenies 31 x 751.						
31 x 751	4	16	144	134	167	166
31 x 751	1	36	115	143	178	180
Michikof x Ind. Swamp Sel. 3, Progenies 610 x 380.						
610 x 380	4	27	96	98	92	90
610 x 380	1	39	83	104	97	102
Wheedling x Ind. Swamp Sel. 3. Progenies 3 x 380.						
3 x 380	4	13	87	88	91	86
3 x 380	1	19	83	104	97	102
Hardy Northern x Ind. Swamp Sel. 3, Progenies 613 x 380.						
613 x 380	4	22	90	92	86	97
613 x 380	1	17	105	104	121	161
Garnet x Prelude.						
Garnet x Prelude	4	43	105	103	111	105
Garnet x Prelude	1	163	77	66	80	81

The other nine crosses grown in this 1-inch spacing test included such small numbers of plants that the results obtained merely indicated their yielding ability. Four of these were slightly better than the high parent, four intermediate, and one the same as the low parent in yielding ability.

Careful observation of the crosses growing in this 1-inch spacing plat revealed no outstanding or significant superiority of the hybrid over either parent row in any character, except in one or two cases a slight increase in plant height. Differences observed and measured resembled rather those that would be found in a similar plat planted to fairly similar varieties of winter wheat.

Table 4 shows the reaction of the hybrid under the 4- and 1-inch spacing rates compared with the parental average as 100%. Some interesting reactions are revealed by these data. It can be readily seen that, in general (9 of the 13 crosses), the hybrids developed better when spaced 4 inches apart than when spaced 1 inch apart in the row. Four crosses (31%), however, showed the opposite reaction, producing relatively better F_1 plants when spaced 1 inch in the row than when spaced 4 inches apart in the row. The crosses were, as a rule, fairly uniform in their reaction to the two spacings, being below the parental average in only 6 of the 26 cases. In other words, in 77% of the cases the hybrids were higher than the parental averages. These data, taken from parents and hybrids growing under nearly normal drilled field conditions, indicate little heterosis among the hybrids studied. The small amount of hybrid vigor revealed by testing parents and F_1 hybrids under these two spacing conditions and by using fairly large numbers, considering the difficulty of producing the seed, seems scarcely measurable. It is certainly of no economic value as such unless obtained in homozygous vigorous individuals of later generations.

The relatively large number of individuals used in these experiments may be worthy of mention. In obtaining the data comparing the plant characters of the hybrids and parents when spaced 4 inches apart in the row, 705 hybrid and 909 parent plants were studied. In the 1-inch spacing, 885 hybrid and 1,783 parent plants were studied. Totals, then of 1,590 hybrid and 2,692 parent plants were used in making the comparisons presented in this paper.

SUMMARY

In order to study the degree and prevalence of hybrid vigor consequent upon crossing pure lines of common wheat, F_1 hybrids and their parents were grown side by side and compared in the following

characters: (a) Date in pollen, (b) tillers per plant, (c) tillers bearing spikes, (d) plant height in inches, (e) plant weight, (f) grain weight, (g) spike weight, and (h) date ripe. Only the first six characters are treated in this paper.

In making the comparisons reported in this article, a total of 26 different crosses, including 1,590 hybrid and 2,692 parent plants, was studied during the 3-year period 1927–29.

The weight of the whole plant minus the roots was considered to be the best criterion of heterosis, since it is the best measure of the final result of the metabolism of the plant.

Enough F_1 crossed seed of 13 different crosses was produced in 1928 to plant a rod row spaced 4 inches and also to plant from 1/5 to 2 1/5 rod rows spaced 1 inch apart in the row. Hybrids compared with their parents under these two spacing conditions gave fairly consistent results, though, in general, the hybrids developed relatively better when spaced 4 inches than when spaced 1 inch apart.

Observations of hybrids and parents grown in the 1-inch spacing plat revealed no pronounced examples of hybrid vigor, but differences observed and measured resembled rather those which would be found in a similar plat planted to fairly similar varieties.

Data taken upon individual plants grown 4 inches apart in the row showed earliness, high tillering ability, numerous spikes per plant, tallness, high yield per plant, and high grain yield to be partially dominant over low values for these characters. Partial dominance of these characters was considered a mark of hybrid vigor.

Some degree of increase in F_1 above the parental average or above the high parent was a fairly common phenomenon. The magnitude of this increase, however, was seldom sufficient to be significant. Of the 26 crosses studied, 16, or 61%, were consistently better than the parental average; and 8 of these were mathematically significant. Disregarding maturity, 9, or 35%, were consistently above the higher parent in all characters studied; and 2 of these showed mathematical significance.

Decreases below the parental average or below the low parent were often shown by the F_1 hybrids. Four crosses were consistently lower than the parental average in all characters except plant height. The hybrid was lower than the parental average in 14% and as low as or lower than the low parent in 6% of the total instances.

The assumption that two or three incompletely dominant factors which depress growth are found among pure lines of *vulgare* wheat will explain the frequency of occurrence of decreases in the F_1 below the parental average and below the low parent.

Increases in F_1 above the higher parent can be explained by assuming each parent to carry different, partially dominant, favorable growth factors which, combined in the F_1, cause vigor above that of either parent.

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CORRELATION OF FACTORS AFFECTING YIELD IN HARD RED SPRING WHEAT[1]

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In planning for the production of an improved variety, the small grain breeder may cross two or more varieties with the hope of combining in a single variety the desirable characters of several. It is a common practice to use as one parent, at least, a variety which excels in yielding ability as determined by yield trials. The other parent should be selected because it contains a certain desired character or characters which are lacking in the standard variety.

Yield in small grains is apparently a complex character influenced by such factors as plumpness of grain, number of kernels per spike or panicle, reaction to disease, lodging, number of spikes or panicles per unit area, and period of maturity. Insufficient information is available concerning the extent to which various characters influence yielding ability and the extent to which two or more of these agronomic characteristics are conditioned by the same genetic factor or factors.

This report comprises a statistical study of the relation between various plant characteristics and yielding ability of hard red spring wheat grown in rod rows at the Morris, Minnesota, Branch Experiment Station during the crop season of 1929.

REVIEW OF LITERATURE

Goulden and Elders (1),[3] in a study of numerous varieties and selections grown in rod-row trials at the Dominion Rust Laboratory at Winnipeg, Canada, obtained significant negative correlation coefficients between yield and susceptibility to stem and leaf rust. Early heading varieties yielded higher than those heading later. Total and partial correlation coefficients were used to analyze the importance of the different factors concerned.

Hayes, Aamodt, and Stevenson (2) studied spring and winter wheat varieties grown in rod-row trials and Immer and Stevenson (3) made similar studies with oats. Partial and multiple correlation

[1]Contribution from Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Paper No. 975 of the Journal Series. Received for publication October 23, 1930.

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[3]Reference by number is to "Literature Cited," p. 117.

coefficients were used. In these three crops, plumpness of grain was strongly correlated with yielding ability. Plumpness of grain was strongly negatively correlated with percentage of stem rust infection in spring and winter wheat and with percentage of crown rust infection in oats to the extent of $-.48 \pm .03$ when date heading and lodging were held constant. In spring and winter wheat, respectively, plumpness of grain and yield were correlated to the extent of $.47 \pm .07$ and $.56 \pm .09$ when stem and leaf rust were held constant. This emphasized the importance of selecting for plumpness of grain during the early segregating generations.

Multiple correlation coefficients were calculated to determine the extent in spring and winter wheat to which yield was a function of the variables date heading, height of plant, percentage infection of stem and leaf rust, and plumpness of grain. In addition, winter injury was studied also in winter wheat. The multiple correlation coefficients were .66 and .90, respectively. In oats, multiple correlation coefficients were calculated for yield in relation to plumpness, date heading, height, crown rust reaction, and lodging. The calculated values at University Farm, Waseca, and Morris were .91, .83, and .79, respectively. From 43 to 82% of the total squared variability was accounted for in these studies.

Waldron (4) made a study of certain varieties and hybrids of spring wheat grown at Langdon and Fargo, respectively, with particular reference to the correlation between yield and fertile spikelets per head, sterile spikelets, kernels per head, mid-kernels per spikelet, weight of grain per 50 heads, and weight per 1,000 kernels. He points out that Biffin believes number of kernels per spikelet and spike to be important characters. The results presented by Waldron indicate that varieties which produce a larger number of kernels per head are desirable. Waldron presents data which indicate that this character, which he terms prolificacy, was probably inherited from Kota. Hybrids produced from Kota crosses proved more fruitful than Kota and especially more fruitful than ordinary spring wheats.

MATERIALS AND METHODS

The study was conducted with 61 strains of varieties of spring wheat, each of which was grown in three systematically distributed plats of three rod rows each at the West Central Experiment Station at Morris. This station is immediately south of the Red River Valley and in a section where spring wheat is grown extensively as a cash crop. Seasonal conditions in 1929 were fairly satisfactory for small grain at Morris and good yields were obtained.

Yields and other data were secured from the central rows of each plat and the average determined for three systematically distributed plats of each variety. Notes were taken and studies made on yield, height of plants, number of heads per row, percentage of stem and leaf rust, number of kernels per spike, number of kernels per spikelet, sterile spikelets, weight of 1,000 kernels, plumpness of kernels in percentage, and date of heading. Separate determinations for each character were made for each plat and the averages used in making the correlation studies.

No appreciable amount of lodging was prevalent so this variable was not used. Yield is expressed in bushels per acre, height in inches, plumpness in percentage with 100 as a perfect score, and heading date in days. The central row of each plat was harvested and total number of culms counted. Fifty heads were taken at random from each row harvested and data on number of kernels per spike, number of kernels per spikelet, and number of sterile spikelets secured from these. As all of the lines grown, except Marquis, had been selected for resistance to stem rust, the average amount of infection recorded was found to be too small to be of much consequence in modifying yield. Leaf rust infection was severe, offering a good opportunity to study its importance with regard to yield and other characters.

In making this correlation study, simple correlation coefficients were used to express the relationship between two variables. All calculations were carried to four places, but only two places are presented. Partial correlations were used to measure the relationship between two variables holding constant one or more other variables. Multiple correlation coefficients were used to measure the effect of several independent variables on a single dependent variable. Probable errors of the correlation coefficients were calculated using the formula P. E. $= \pm .6745 \frac{1-r^2}{\sqrt{N}}$, where N is the total frequency. Unity was subtracted from N for each variable eliminated in calculating the P. E. of the partial correlations. As the results for each character are an average of three determinations, the usual probable error formula was used to determine the significance of the correlation coefficients.

The 61 varieties comprised the standard parental types, Marquis, Marquillo, the two Marquis x Emmer crosses, Hope and H-44, which were produced by McFadden, Ceres, and the Kanred x Marquis selection; 26 double crosses which were obtained from purified crosses of (Kanred x Marquis) with (Iumillo, a durum wheat x Marquis); 13 crosses of Marquillo x Marquis or Red Bobs; 1 selection of Kota x

Webster; and 15 selections of Kota x Marquis, 10 of which were made by Dr. L. R. Waldron of the North Dakota Experiment Station from N. D. 1656. The data, consisting as they do of information regarding a wide range of wheat types and of the sorts commonly used at present by plant breeders interested in the spring wheat breeding program, are of considerable general interest.

EXPERIMENTAL RESULTS

A condensed summary of the results obtained is given in Table 1. This consists of data on percentage plumpness of grain, percentage infection of stem and leaf rust, number of heads per row, kernels per spike and spikelet, weight of 1,000 kernels, and calculated yield in bushels per acre. The range of variability and average for the different characters is given for the varieties belonging to the particular groups, N. D. 1656 and 12 selections from this variety, the 13 Marquillo x Marquis and Red Bobs crosses, and the 26 double crosses.

Marquis was injured by stem rust and the seed was somewhat shriveled as compared with Ceres and Marquillo. All of the varieties in the trial were highly resistant to stem rust, except Marquis and the Kanred Marquis selection, II-17-40. Hope and H-44 were resistant to leaf rust. One of the double crosses, a Kota-Webster cross and a Kota-Marquis cross showed some resistance to leaf rust, while the remainder of the selections ranged from moderately susceptible to very susceptible.

The N. D. selection 1656 and its derivatives were outstanding in percentage plumpness of grain and the Minnesota double crosses were also very exceptional in this respect. Ceres, three Kota crosses, N. D. 1656, and selections from this variety excelled in the number of kernels per spike and spikelet, while the Minnesota double crosses, the Kanred-Marquis selection, Hope, and H-44 were inferior in this regard.

The number of heads per row, which is a measure of tillering ability, of the N. D. 1656 selections and the other Kota-Marquis crosses was relatively low, while Hope, Marquillo, H-44, and most of the double crosses excelled in this respect. These facts emphasize the difficulty of analyzing the factors responsible for high yielding ability.

SIMPLE PRODUCT MOMENT CORRELATIONS

The simple product moment correlation coefficients between the various characters are presented in Table 2. It will be noted that height and plumpness of grain are correlated more highly with yield than any of the other variables studied. Yield with height are a correlation coefficient of $.43 \pm .07$ and yield with plumpness $.43 \pm .07$.

TABLE 1.—*Percentage of plumpness of grain, percentage of leaf and stem rust infection, number of heads per rod row, kernels per spike and spikelet, weight per 1,000 kernels, and yield in bushels per acre of 61 strains of spring wheat grown at the West Central Station in 1929.*

Origin	No. of lines	% plumpness		% stem rust		% leaf rust		Heads per row	
		Range	Av.	Range	Av.	Range	Av.	Range	Av.
Marquis	1	——	61	——	68	——	87	——	440
Marquillo	1	——	78	——	14	——	63	——	498
Ceres	1	——	80	——	20	——	88	——	414
Hope	1	——	85	——	1	——	8	——	552
Marquis x Emmer (H-44)	1	——	83	——	1	——	12	——	585
Kanred x Marquis (II-17-40)	1	——	80	——	38	——	85	——	486
Kota x Webster	1	——	82	——	11	——	13	——	407
Kota x Marquis	2	80–82	81	3–18	11	33–88	61	383–400	392
N. D. 1656 and selections	13	72–90	86	10–27	18	73–85	80	344–461	404
Marquillo x Marquis and Red Bobs	13	62–83	77	10–21	14	88–93	89	358–503	438
Double crosses	26	78–93	89	5–19	14	25–90	81	448–610	535

Origin	No. of lines	Kernels per spike		Kernels per spikelet		Weight per 1,000 kernels, grams		Yield, bushels per acre	
		Range	Av.	Range	Av.	Range	Av.	Range	Av.
Marquis	1	——	28	——	1.5	——	21.7	——	23.9
Marquillo	1	——	26	——	1.6	——	26.1	——	26.4
Ceres	1	——	31	——	1.8	——	27.0	——	24.6
Hope	1	——	23	——	1.3	——	29.2	——	25.8
Marquis x Emmer (H-44)	1	——	20	——	1.3	——	22.2	——	29.8
Kanred x Marquis (II-7-40)	1	——	23	——	1.4	——	27.9	——	27.9
Kota x Webster	1	——	30	——	1.8	——	26.9	——	25.4
Kota x Marquis	2	33–35	34	1.9–2.0	1.9	25.2–27.0	26.1	24.4–29.6	27.0
N. D. 1656 and selections	13	24–35	30	1.4–1.9	1.7	26.8–35.1	29.2	22.5–31[illegible]	26.8
Marquillo x Marquis and Red Bobs	13	22–28	26	1.4–1.7	1.5	21.8–30.0	25.9	16.7–29.5	21.9
Double Crosses	26	20–26	24	1.3–1.7	1.5	21.0–34.7	26.5	18.8–29.6	25.3

TABLE 2.—*Interrelationship of characters as shown by simple product moment correlation coefficients.*

Characters correlated	Correlation coefficient
Yield and	
Plumpness	.43±.08
Weight of 1,000 kernels	.38±.07
Date heading	.27±.08
Height	.43±.07
Heads per row	.19±.08
Black stem rust	.06±.09
Leaf rust	—.27±.08
Kernels per spike	.18±.08
Kernels per spikelet	.19±.08
Plumpness and	
Weight of 1,000 kernels	.36±.08
Date heading	.43±.07
Height	.06±.09
Heads per row	.40±.07
Black stem rust	—.38±.07
Leaf rust	—.06±.09
Kernels per spike	—.28±.08
Kernels per spikelet	—.13±.08
Weight of 1,000 kernels and	
Date heading	.23±.08
Height	.06±.09
Heads per row	—.23±.08
Stem rust	—.13±.07
Leaf rust	—.07±.09
Kernels per spike	.09±.09
Kernels per spikelet	.10±.09
Date heading and	
Height	—.61±.05
Heads per row	.36±.07
Stem rust	.15±.09
Leaf rust	—.36±.08
Kernels per spike	—.21±.08
Kernels per spikelet	—.21±.08
Height and	
Heads per row	—.15±.08
Stem rust	.18±.08
Leaf rust	—.23±.08
Kernels per spike	.45±.07
Kernels per spikelet	.46±.06
Heads per row and	
Stem rust	—.23±.08
Leaf rust	—.10±.09
Kernels per spike	—.72±.04
Kernels per spikelet	—.61±.05
Stem rust and	
Leaf rust	.30±.09
Kernels per spike	.25±.08
Kernels per spikelet	.15±.08

TABLE 2—*Continued.*

Characters correlated	Correlation coefficient
Leaf rust and	
Kernels per spike	$.03 \pm .09$
Kernels per spikelet	$.03 \pm .09$
Kernels per spike and	
Kernels per spikelet	$.93 \pm .01$
Sterile spikelets	$.28 \pm .08$

A significant correlation of $.38 \pm .07$ was secured between yield and weight of 1,000 kernels. Waldron (3) reports similar results from studies made in North Dakota. The later heading types showed a tendency to yield more than the earlier heading ones, as is brought out by the correlation of $.27 \pm .08$ between yield and date heading. Leaf rust infection and yield were negatively correlated to the extent of $-.27 \pm .08$ which is considered significant when compared with three times its probable error. No positive evidence was found that the number of heads per row was a factor directly influencing yield as the correlation of $.19 \pm .08$ is of doubtful significance.

Plumpness was correlated negatively with number of kernels per spike with a correlation coefficient of $-.28 \pm .08$. Analyses of the relationships existing between plumpness and the other variables show that plumpness was correlated with date of heading to the extent of $.43 \pm .07$, a logical relation in view of a similar one between yield and date heading. Weight of 1,000 kernels was also associated with plumpness as shown by a correlation of $.36 \pm .08$. A rather strong correlation of $.40 \pm .07$ was observed between number of heads per row and plumpness. This is an interesting relationship and possibly may be explained on the basis that the same growth factors have an influence on these two characters.

The relationships of heading date with either yield or plumpness are positive. It is assumed that date of heading influenced the weight of 1,000 kernels to some extent. A correlation of $.23 \pm .08$ indicates that the later heading strains were somewhat superior in weight of kernel. The character date of heading was correlated negatively with height to the extent of $-.61 \pm .05$, also with leaf rust $-.36 \pm .08$, and positively correlated with number of heads per row, $.36 \pm .08$, all three correlations being more than three times their probable errors. From these it may be assumed that the earlier types were taller and more strongly infected with leaf rust but showed a tendency to have a smaller number of heads per row.

Stem rust is without doubt an important factor affecting plumpness of grain as evidenced by a correlation of — .38 ± .07. Hayes, *et al.* (2) obtained similar but more striking results with winter and spring wheat.

Height is correlated with number of kernels per spike to the extent of .45 ± .07 and with number of kernels per spikelet, .46 ± .06. This probably explains a part of the positive relationship that was obtained between height and yield. The shorter strains, however, were more susceptible to leaf rust, as indicated by the correlation of — .23 ± .08 between height and leaf rust.

Comparing the relationships of number of heads per row with other variables reveals striking negative correlations of —. 72 ± .04 with kernels per spike and — .61 ± .05 with the number per spikelet.

Stem rust showed a relationship with leaf rust of .30 ± .09 and .25 ± .08.

The number of kernels per spike is almost perfectly correlated with the number of kernels per spikelet, as indicated by a correlation of .93 ± .01.

The following interrelationships are considered of little significance since the correlation coefficients were found to be approximately two times the probable error:

Yield with number of heads per row.
Yield with number of kernels per spike.
Yield with number of kernels per spikelet.
Plumpness with number of kernels per spikelet.
Weight of 1,000 kernels with stem rust.
Date of heading with stem rust.
Date of heading with kernels per spike.
Date of heading with kernels per spikelet.
Height with heads per row.
Height with stem rust.
Heads per row with leaf rust.
Stem rust with kernels per spikelet.

Correlation coefficients of approximately once the probable error were obtained between the following variables:

Yield with stem rust.
Plumpness with height.
Plumpness with leaf rust.
Weight of 1,000 kernels with height.
Weight of 1,000 kernels with leaf rust.
Weight of 1,000 kernels with kernels per spike.
Weight of 1,000 kernels with kernels per spikelet.

PARTIAL CORRELATIONS

For the purpose of determining the true relationship between a few of the variables, partial correlation coefficients were calculated. These give the direct relation between two factors holding constant the other variables under consideration.

Partial correlations for yield with height, plumpness, heading date, weight of 1,000 kernels, and heads per row are given in Table 3.

TABLE 3.—*Comparison of simple product moment correlation coefficients and partial correlation coefficients in hard red spring wheat with the multiple correlation coefficient of yield with five other characters.*

Product moment correlation characters correlated	Correlation coefficient	Partial correlations*	Correlation coefficients
Yield and height	$.43 \pm .07$	$r_{15.43269}$ =	$.56 \pm .06$
Yield and plumpness	$.42 \pm .07$	$r_{12.34569}$ =	$-.12 \pm .09$
Yield and date of heading	$.27 \pm .08$	$r_{14.32569}$ =	$.52 \pm .07$
Yield and weight of 1 000 kernels	$.38 \pm .07$	$r_{13.24569}$ =	$.22 \pm .07$
Yield and number of heads per row	$.19 \pm .08$	$r_{16.43259}$ =	$.02 \pm .09$
Yield and kernels per spike	$.18 \pm .08$	$r_{19.43256}$ =	$.09 \pm .08$
		$r_{18.4}$ =	$-.18 \pm .08$
		$r_{14.6}$ =	$.21 \pm .08$
		$r_{16.4}$ =	$.10 \pm .09$
		$r_{1.234569}$ =	$.81 \pm .05$

*1 = yield, 2 = plumpness, 3 = weight of 1,000 kernels, 4 = date heading, 5 = height, 6 = heads per row, 8 = leaf rust, 9 = kernels per spike.

There was a rather striking positive correlation ($r_{15.43269} = .56 \pm .06$) between yield and height of plants, holding constant date of heading, weight of 1,000 kernels, plumpness, number of heads per row, and number of kernels per spike. This gives a more accurate relationship of yield with height when other factors are held constant and is in accord with the simple correlation of $.43 \pm .07$ for the same pair of factors.

The partial coefficient of correlation of yield and plumpness of kernel, holding constant weight of 1,000 kernels, date of heading, height, heads per row, and number of kernels per spike, was $-.12 \pm .09$. This would seem to indicate that plumpness was directly affected by these other factors. This might have been expected because there was appreciable positive correlation for plumpness with each of the characters, weight of 1,000 kernels, date heading, and heads per row.

Date of heading was correlated with yield to the extent of $r_{14.32569} = .52 \pm .07$ when weight of 1,000 kernels, percentage plumpness, height, heads per row, and kernels per spike were held constant. Date of heading apparently is associated more closely with yield when other conditions are controlled than the simple product moment

correlation of .27 ± .08 showed. The relation of yield with heads per row and yield with kernels per spike, where other variables were held constant, was not significant.

It will be remembered that yield with weight of 1,000 kernels showed a correlation of .38 ± .07. By holding constant the effects of plumpness, date of heading, height, heads per row, and kernels per spike, a correlation coefficient of $r_{13.24569}$ = .22 ± .07 was obtained which is barely significant when compared with three times its probable error.

Partial correlations of yield with leaf rust, holding constant date of heading, gave a correlation coefficient of — .19 ± .08; yield with heads per row, holding constant date of heading, a correlation of .10 ± .09; and yield with date of heading, holding constant heads per row, a correlation of $r_{14.6}$ = .21 ± .08.

The multiple correlation $r_{1.234569}$, or the correlation of plumpness, weight of 1,000 kernels, date of heading, height, number of heads per row, and number of kernels per spike in relation to yield, was .81 ± .05. This shows that 66% of the total squared variability in yield can be explained in terms of the mathematical relation with the other characters.

DISCUSSION

An investigation of this kind entails the accumulation of a large amount of data. In order to analyze these the results must be reduced to a convenient size for interpretation in order that the relevant information of the mass may be explained in terms of a few numerical values. To know for instance whether an observed difference in yielding ability between different selections or varieties is due to cultural practices, environmental conditions, or to inherent characteristics of the strains is very valuable from the standpoint of further selections. Suitable statistical methods must be applied to the data in order to secure correct interpretations. Correlation coefficients offer the most suitable means and were used in this study.

An interpretation of the various coefficients has been made on the data presented. In an analysis of these data, however, it must be borne in mind that the material used was rigidly selected strains of hard red spring wheat which were being tested as one phase of the breeding program. For this reason it is quite possible that the rigid selection for stem rust resistance affected other characters.

The Kota crosses, N. D. 1656, and selections from it excelled in number of kernels per spike, while the Minnesota double crosses were inferior in this respect. The Minnesota double crosses excelled in

heads per row, while the Kota crosses lacked stooling ability. As some of the double crosses and several of the N. D. 1656 selections gave high yields, the correlations between yield and kernels per spikelet and between yield and heads per row were not significant. Number of heads per row was correlated with plumpness of grain, a character which is strongly correlated in small grains with yielding ability.

It seems reasonable to believe that the Minnesota double crosses should combine well with H-44 and Hope to produce a high yielding variety resistant to diseases. Such a variety would lack prolificacy as expressed by kernels per head. This character may be obtained from Kota derivatives. A Marquis-Kota cross which excelled in this respect used as a parent with Hope or H-44 could be expected also to furnish desirable material for selection purposes. A combination of the desirable characters of Kota crosses with the growth vigor of the Minnesota double crosses and with the disease resistance of Hope and H-44 appears to give greatest promise.

Crosses of Marquillo, Hope, and H-44 with Marquis can not be expected to be very outstanding in growth vigor as expressed by heads per row or plumpness of grain or kernels per head and spikelets. Numerous crosses of Marquillo x Marquis and H-44 x Marquis have been produced in Minnesota without obtaining an outstanding variety from the standpoint of yielding ability.

SUMMARY OF RESULTS

1. Eleven characters were studied of 61 hard red spring wheat strains grown in rod-row trials at the Morris Branch Station in Minnesota.

2. Within these characters yield was correlated positively with plumpness of grain, weight of 1,000 kernels, date of heading, and height and was correlated negatively with leaf rust.

3. Plumpness of grain was positively correlated with weight of 1,000 kernels, date of heading, number of heads per row, and negatively correlated with stem rust and kernels per spike.

4. Date of heading showed positive correlations with heads per row. Negative correlations were obtained with height and leaf rust.

5. Height was correlated positively with kernels per spike and kernels per spikelet and negatively with leaf rust.

6. Number of kernels per head and spikelet, growth vigor as expressed by heads per row and by plumpness of grain combined with resistance to disease should give an ideal variety of spring wheat. Such a combination should be obtained from the characters found in

the N. D. 1656 selections, the Minnesota double crosses, and the McFadden selections from crosses of Marquis with Emmer.

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A STATISTICAL STUDY OF WHEAT AND OAT STRAINS GROWN IN ROD-ROW TRIALS[1]

F. R. IMMER AND E. R. AUSEMUS[2]

A knowledge of the factors affecting yield is essential for the rapid and efficient solution of any plant breeding problem. The constancy of reaction of varieties and strains under different environmental conditions and even at the same place in successive years is also of primary importance. Although the study of factors affecting yield is a very old one, reliable data are still rather meager. More information on the constancy of reaction of the same varieties of small grains under different environmental conditions is also highly desirable.

The analysis of data from a large number of varieties and strains can be made only by the use of the statistical method. The data must be reduced until as much as possible of the relevant information can be conveyed by a comparatively few biometrical constants. In the present study, the correlation coefficient is used in studying the constancy of reaction of strains of wheat and oats grown in different places in Minnesota or in the same locality in successive years and the effect on yield of certain strain characteristics and disease factors.

REVIEW OF LITERATURE

From studies on three varieties of bread wheats grown in different climatic regions and crop years, Sprague (7)[3] found that yields per acre and the means of the culm and spike characters varied widely with climatic conditions and variety. In Nebraska No. 60 wheat

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. The studies of disease resistance are a phase of the cooperative studies conducted by the Divisions of Agronomy and Plant Genetics and Plant Pathology and Botany, Minnesota Agricultural Experiment Station. All of the phases of breeding of spring and winter wheat are conducted cooperatively by the Minnesota Agricultural Experiment Station and the Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Published with the approval of the Director as Paper No. 974 Journal Series of the Minnesota Agricultural Experiment Station. Received for publication October 23, 1930.

[2]Associate Geneticist, Office of Sugar Plants, U. S. Dept. of Agriculture, formerly Assistant Plant Geneticist, University of Minnesota; and Associate Agronomist, Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture, respectively. The writers wish to express their thanks to Dr. H. K. Hayes for constructive criticism in relation to this study.

[3]Reference by number is to "Literature Cited," p. 131.

grown at Lincoln, Neb., he found a high positive correlation between yield per unit area and average number of spikes per area. Smaller positive correlations were found for yield per unit area with grain yield per spike and weight per kernel.

Goulden and Elders (3) found definite evidence of a negative correlation between yield and susceptibility to stem rust, date of heading, and strength of straw from rod-row trials of spring wheat. A negative relationship was also obtained between yield and susceptibility to leaf rust. Both zero and third order correlation coefficients were used in making the analysis.

Hayes, Aamodt, and Stevenson (4), from correlation studies on data from rod rows of spring and winter wheat, found stem and leaf rust, date of heading, height of plants, and percentage plumpness of grain to be of importance in relation to yielding ability in spring wheat. Yielding ability in winter wheat was found to be significantly and positively associated with plumpness of grain and height of plant and negatively with winter injury. The value of the plumpness note as an index of yield during the early generations of the breeding trial was emphasized.

Immer and Stevenson (5) found plumpness of grain, heading date, crown rust reaction, and lodging to be closely associated with yielding ability in oats.

Bridgford (1) found yield in rod rows of wheat grown at Morris, Minnesota, to be positively correlated with plumpness, weight of 1,000 kernels, heading date, height of plants, and number of sterile spikelets and correlated negatively with reaction to leaf rust. Partial correlation coefficients were used to bring out the relationships between the various factors in the three studies mentioned above. Immer and Stevenson (5) found yields of the same strains of oats grown at University Farm, Waseca, and Crookston to be highly correlated, while the yields at Morris were not strongly correlated with those at University Farm or Crookston.

Quisenberry (6) studied the data obtained from samples of spring and winter wheats taken from fields in Oklahoma, Nebraska, Kansas, and Montana and found number of heads per unit area, number of kernels per spike, and weight of 1,000 kernels to be important factors in determining yield.

From a correlation study on data obtained from rod rows of spring wheats grown at Fargo, North Dakota, in 1928, Waldron (10) found yield to be positively and significantly correlated with number of fertile spikelets per head, weight of grain per 50 heads, and weight of 1,000 kernels. From data obtained at Langdon, North Dakota,

positive and significant correlation coefficients were found between the same characters as well as between yield and total number of kernels per head and mid-kernels per head and a significant negative correlation between yield and number of sterile spikelets per head.

Waldron (8, 9) also studied the reaction of wheat varieties and strains in cooperative rod-row trials in North Dakota in 1927 and 1928. From 21 correlation coefficients calculated from yields obtained from 10 varieties grown in seven places in western North Dakota, a positive and significant correlation coefficient for yield between the different places was obtained in 14 cases when the conventional probable error method was used to determine the significance of the coefficient. From 21 similar comparisons between 10 varieties grown in eastern North Dakota, 11 of the coefficients were significant.

MATERIALS AND METHODS

The data used for this study were obtained from uniformly replicated rod-row trials of hard red spring wheat, durum wheat, and oats. In most cases the material was grown in three replicated plats of three rod rows each. Notes were taken and yields obtained on the central row of each three-row plat and the average obtained for the three plats of a given strain or variety. These averages for each strain were then used in making the analysis.

These rod-row trials were conducted at University Farm, in east central Minnesota, and at the three branch experiment stations located at Waseca, in southeastern Minnesota, Crookston in northwestern Minnesota, and Morris, in west central Minnesota. The trials at these branch experiment stations are a part of the regular plant breeding program as the same varieties and strains are grown at all the stations each year.

The material grown in the rod rows at the branch stations was harvested under the supervision of the superintendent or agronomist in charge of the particular station and sent to University Farm to be threshed, weighed, plumpness of grain notes taken, and yields calculated.

Yield data were obtained from the central row of the three-row plats. The plumpness note was taken on a percentage basis where 100 represents maximum plumpness of kernels. This note was recorded after visual inspection of the sample of threshed grain.

The material in these rod row trials was selected in the sense that at least a part of the strains had been tested previously and the undesirable strains discarded. Selection had been made for plumpness of grain throughout the segregating generations following a cross.

Selection for rust resistance also had been made prior to the rod row trials and the most susceptible material discarded. It would be more reliable to make such a study for unselected material. The cost of using unselected material precludes such a mode of attack. The study was made, therefore, with the material available which was being grown for the purpose of obtaining more desirable varieties for commercial production than are now available.

Studies were made by means of the correlation coefficient of the relationship between yield, plumpness of grain, date of heading, and rust reaction in hard red spring wheat, durum wheat, and oats grown at University Farm, Waseca, Crookston, and Morris. Inter-annual correlations were also determined between the same characters on the same strains grown at the same station in successive years. Finally, inter-station correlations were calculated in which the reaction of the same strains grown at different stations the same year were determined.

The significance of the correlation coefficients was judged according to the method suggested by Fisher (2). A correlation coefficient was considered significant if P, the probability of exceeding the observed value through random sampling, was less than .05. All correlation coefficients which were significant are italicized in the tables which follow. In averaging correlation coefficients, they were transformed into the "Z" distribution given by Fisher and the "Z's" averaged, and then the average "Z" transformed back to "r." While the "Z" distribution is not strictly normal, it is much more so than the distribution of "r." In judging the significance of the difference between correlation coefficients, the respective values of "Z" were compared in the light of the standard error of "Z."

The summary of data is presented under three heads, *viz.*, (a) the interrelationships between yield, plumpness, heading date, and rust reaction the same year at the same station; (b) the inter-annual correlations between the same character for strains grown in two successive years; and (c) the inter-station correlations between the same characters for the same strains grown at four different places in Minnesota the same year.

EXPERIMENTAL RESULTS

CORRELATION BETWEEN CHARACTERS AT THE SAME STATION

In Table 1 are given the inter-character correlation coefficients for hard red spring wheat strains and varieties grown at each of four stations, covering a period of 5 years.

TABLE 1.—*Correlations between characters of the same strains and varieties of spring wheat grown at four stations the same years.*

Year	No. of strains	Characters correlated*									
		Yield and				Plumpness and			Heading date and		Stem rust and leaf rust
		Plumpness	Heading date	Stem rust	Leaf rust	Heading date	Stem rust	Leaf rust	Stem rust	Leaf rust	
						University Farm					
1924..	45	*.36*	—.22			.11					
1925..	70	*.66*	—.21	*.29*		*—.31*	—.04		.19		
1927..	73	*.53*	*—.45*	.07	*—.29*	—.13	—.08	—.09	—.20	.09	*.32*
1928..	70	*.39*	.01			.23					
1929..	61	.15	*—.30*		—.10	*.39*		—.12		*—.26*	
Average		*.45*	*—.24*			.04					
						Waseca					
1924..	45	*.69*		—.05			—.16				
1925..	70	*.71*		.10			—.03				
1927..	73	*.59*	—.10	*—.23*	*—.40*	*.26*	—.13	*—.25*	.18	.16	*.44*
1928..	70	*.53*	—.16			—.04					
1929..	61	*.40*	—.12		—.08	.14		.05		*—.27*	
Average		*.59*									
						Crookston					
1924..	45	*.48*	*—.29*	*—.44*		—.17	*—.59*		—.13		
1925..	70	*.70*	*—.53*	*—.48*		*—.51*	*—.78*		.19		
1927..	73	*.59*	—.01	—.03	*—.23*	*—.33*	*—.31*	*—.27*	*.25*	—.13	.18
1928..	70	*.60*	—.13		—.15	—.21		—.18		.19	
1929..	61	*.50*	*.49*	.08	*—.26*	*.44*	—.07	—.17	—.05	*—.40*	.01
Average		*.59*	—.10			*—.18*					
						Morris					
1924..	45	*.34*	—.13			—.04					
1925..	70	*.65*		*—.49*			*—.78*				
1927..	73	*.63*	.11	—.02	*—.29*	*.41*	.08	*—.37*	*—.67*	*—.42*	.18
1928..	70	*.72*	.17		*—.28*	.22		*—.28*		*—.27*	
1929..	61	*.38*	*.26*	.09	—.23	*.41*	*—.41*	—.09	—.14	*—.39*	*.35*
Average		*.58*									

*Statistically significant correlation coefficients italicized.

The correlation between yield and plumpness of grain is quite high, suggesting, as noted by others (4, 5), the importance of the plumpness note as an index of yield during the early, segregating generations of a cross. Plumpness was more directly associated with yield at Waseca, Crookston, and Morris than at University Farm, the correlation being significantly lower at University Farm than at the other three stations as an average of the 5 years. The data indicate that the earlier wheats were higher yielding at University Farm and at Crookston, except in 1929. There was a slight positive correlation between early heading and yield at Waseca, while the data were conflicting at Morris. In the main, stem rust was negatively associated with yield, although a positive correlation of .29 at University Farm in 1925 is noted. Apparently, in that case, the more rust susceptible strains were potentially higher yielding and the rust epidemic was not severe enough to overbalance this tendency. Leaf rust was negatively correlated with yield in every comparison made. Heading date was both positively and negatively correlated with plumpness in the tests made at University Farm during the 5-year period. At Crookston the earlier strains were the plumpest, except in 1929, and at Morris the later heading strains excelled in plumpness three of the four years considered. In some years date of heading was of importance in relation to stem and leaf rust infection. Stem and leaf rust reaction were positively correlated in each of the six comparisons, although only three of these are statistically significant. This result is probably due to the fact that certain strains, notably Hope and H-44, are highly resistant to both stem and leaf rust, while other strains are very susceptible to both.

TABLE 2.—*Correlations between characters of the same durum wheat strains and varieties grown at four stations the same years.*

Year	No. of strains	Characters correlated*					
		Yield and		Plump-ness and heading date	Yield and		Plump-ness and heading date
		Plump-ness	Heading date		Plump-ness	Heading date	
		University Farm			Waseca		
1927	28	*.60*	*—.71*	*—.38*	*.31*	—.18	.14
1928	42	*.55*	.13	*.36*	*.68*	—.22	—.19
1929	18	*.51*	*—.51*	—.13	.15	—.42	.10
Average....		*.56*	*—.31*	—.03	*.49*	*—.25*	—.03
		Crookston			Morris		
1927	28	—.16	*—.39*	.21	*.45*		
1928	42	*.62*	.11	*.34*	*.58*	*.48*	*.41*
1929	18	.44	—.37	.13	*.48*	—.02	.50
Average....		*.38*	—.15	*.26*	*.52*		

*Statistically significant correlation coefficients italicized.

In Table 2 are given the same comparisons with durum wheats. The number of strains available for the study is somewhat less and only three years are covered.

The correlation coefficients between yield and plumpness were fairly high and of the same order of magnitude as those for hard red spring wheat. There was not a significant difference between the average correlation coefficients between yield and plumpness at the different stations. Date of heading shows about the same relation to yield as was noted for the hard red spring wheats. Earliness was not as closely associated with plumpness of kernels at University Farm, Waseca, and Crookston as yield. At Morris, in 1929, earliness of heading was more closely correlated with plumpness than it was with yield.

TABLE 3.—*Correlations between characters of the same oat strains and varieties grown at four stations the same years.*

Year	No. of strains	Characters correlated*					
		Yield and			Plumpness and		Heading date and crown rust
		Plumpness	Heading date	Crown rust	Heading date	Crown rust	
				University Farm			
1927†	38	*.89*	*—.58*	—.23	*—.57*	—.11	—.29
1928	31	*.41*	*—.38*		—.15		
1929	29	*.38*	.34	.31	.04	—.10	—.07
Average....		*.67*	*—.28*		*—.28*		
				Waseca			
1927†	38	*.77*	—.16	*—.48*	*—.32*	*—.27*	*—.38*
1928	31	*.38*	.12		.07		
1929	29	.35	—.18	*—.51*	*—.51*	—.20	—.02
Average....		*.56*	—.08		*—.27*		
				Crookston			
1927†	38	*.78*	—.26	*—.39*	—.25	*—.43*	*—.30*
1928	31	*.43*	—.04	—.32	.01	*—.49*	—.15
1929	29	*.48*	*.46*		*.39*		
Average....		*.61*	.03		.02		
				Morris			
1927†	38	*.58*					
1928	31	*.53*	*—.37*		*—.47*		
1929	29	.36	—.06	—.18	—.06	.08	—.22
Average....		*.51*					

*Statistically significant correlation coefficients italicized.
†Reported previously by Immer and Stevenson (5).

In Table 3 a similar comparison is made with strains of oats. These strains of oats were tested in rod-row yield trials in 1927 for the first time. Selection on the basis of a regular yield trial had not been made previously. The lowest yielding strains were discarded in the

spring of 1928 and only the more desirable material continued. Further selection and discarding was made in the spring of 1929. While the correlation between yield and plumpness was high in most cases, it is noteworthy that it was highest in 1927 when no yield selection had been made previously. In general, the correlation coefficients decreased as selection continued and more undesirable material was eliminated.

On the average, the correlation between yield and plumpness was not significantly different at the several stations. The earlier strains were the higher yielders in two of the three years at University Farm. Date of heading was not appreciably correlated with yield at Waseca or, on the average, at Crookston. The later heading strains yielded the best at Crookston in 1929. The earlier strains were higher in yield at Morris in one of the two years studied, while the other correlation coefficient was not significant.

Crown rust infection was negatively associated with yield in every comparison except in 1929 at University Farm, although this coefficient .31, because of small numbers, is not statistically significant. Plumpness and heading date were associated to essentially the same degree as yield and heading date, except at Waseca, where earliness was more closely associated with plumpness than with yield. The earlier strains were affected more by crown rust than the later strains, although only two of the seven correlation coefficients are statistically significant.

INTER-ANNUAL CORRELATION

In Table 4 are given the inter-annual correlation coefficients between the reaction of the same hard red spring wheat strains grown at the same station during two successive years.

The influence of environmental conditions and diseases on yield were similar at University Farm, Waseca, and Crookston in 1924 and 1925, but quite dissimilar at Morris, the correlation coefficient for the latter being — .29. Conditions for yield seem to have been quite similar at University Farm and Waseca in 1925–26 and unlike at University Farm in 1927–28. In the comparison of 1928–29 a significant positive correlation coefficient was obtained at University Farm but not at the three branch stations.

In general, plumpness in successive years was more highly correlated than was yield. Date of heading was strongly correlated in a positive manner. Stem and leaf rust also were positively associated in each instance.

In Table 5 are given the inter-annual correlation data for durum wheats and oats.

TABLE 4.—*Inter-annual correlations between the same characters of the same hard red spring wheat strains and varieties grown at the same place in two successive years.*

Year	No. of strains	Inter-annual correlations at*							
		U. Farm	Waseca	Crookston	Morris	U. Farm	Waseca	Crookston	Morris
		Yield				Plumpness			
1924–5	32	.34	*.49*	*.59*	—.29	*.39*	.20	*.82*	*.45*
1925–6	45	*.74*	*.58*			*.92*	*.47*		
1927–8	37	—.04				.22			
1928–9	37	*.38*	.13	.17	—.12	*.88*	*.67*	*.56*	.05
	Average	*.42*				*.74*			
		Heading Date				Stem Rust			
1924–5	32						*.88*	*.64*	
1925–6	45	*.92*	*.86*				.26		
1927–8	37	*.94*							
1928–9	37	*.75*	*.86*	*.64*	*.57*				
		Leaf Rust							
1928–9	37			*.43*	.24				

*Statistically significant correlation coefficients italicized.

TABLE 5.—*Inter-annual correlation between the same characters of the same strains and varieties of durum wheat and oats grown at University Farm in each of two successive years.*

Years	No. of strains	Inter-annual correlation coefficients of*		
		Yield	Plumpness	Heading date
		Durum Wheat		
1927–8.......	27	.17	.30	*.78*
		Oats		
1927–8.......	99	*.35*	*.22*	*.91*
1928–9.......	29	*.39*	.06	*.92*

*Statistically significant correlation coefficeints italicized.

Yield in the 27 durum wheat strains and varieties was not appreciably associated in the two years 1927 and 1928. The inter-annual correlation coefficient for plumpness was higher and that for heading date quite high.

The association between yields of oat strains was statistically significant in the two comparisons possible. Date of heading was very highly correlated and plumpness less so.

INTER-SECTION CORRELATIONS

The reaction of strains and varieties of wheat and oats grown in replicated rod-row plats at different stations the same year is of considerable interest. The data for hard red spring wheat strains grown at University Farm, Waseca, Crookston, and Morris during a period of five years are given in Table 6.

The average correlation coefficient between yields of the same material grown at University Farm and Waseca was .37. Yields at Morris were correlated with those at University Farm to a lesser degree, .26, although the difference was not significant. Yields at University Farm and Crookston were correlated to only a slight degree, .11. Waseca yields were more strongly correlated with those of Morris than with those from Crookston, while yields at Crookston and Morris were as strongly correlated as at Waseca and Morris.

Climatic conditions at Crookston, in northwestern Minnesota, are quite unlike those at University Farm or Waseca which are in east central and southeastern Minnesota, respectively. This is reflected in the correlation coefficients between yields at these stations. The high yielding wheats at University Farm and Waseca would not necessarily be the most desirable at Crookston. During a 5-year period there were only four statistically significant correlation coefficients obtained between the yields at University Farm and those at Crookston or at Morris.

TABLE 6.—*Inter-station correlations between characters of the same strains and varieties of hard red spring wheat grown at four stations the same years.*

Year	No. of comparisons	Stations correlated*					Crookston and Morris
		University Farm and			Waseca and		
		Waseca	Crookston	Morris	Crookston	Morris	
				Yield			
1924	45	*.52*	.01	.16	.21	—.06	.11
1925	70	*.46*	.10	.12	*.29*	*.45*	*.69*
1927	73	*.35*	*.25*	*.55*	*.32*	*.44*	*.35*
1928	70	*.33*	*.25*	*.29*	*.41*	*.43*	*.50*
1929	61	.18	—.15	.05	.04	*.56*	.11
	Average	*.37*	*.11*	*.26*	*.27*	*.40*	*.40*
				Plumpness			
1924	45	*.33*	.22	.21	*.61*	—.07	—.24
1925	70	*.54*	.21	.22	*.44*	*.38*	*.84*
1927	73	*.24*	*.33*	*.40*	*.56*	*.62*	*.54*
1928	70	*.71*	*.72*	*.79*	*.76*	*.72*	*.78*
1929	61	.12	*.48*	.22	*.69*	*.72*	*.68*
	Average	*.43*	*.43*	*.43*	*.62*	*.55*	*.64*
				Heading Date			
1924	45		*.52*	*.76*			*.54*
1925	70		*.86*				
1927	73	*.87*	*.83*	*.59*	*.85*	*.56*	*.59*
1928	70	*.88*	*.57*	*.84*	*.56*	*.73*	*.37*
1929	61	*.83*	*.99*	*.66*	*.73*	*.64*	*.61*
				Stem Rust			
1924	45				.19		
1925	70	*.82*	*.83*	*.85*	*.92*	*.91*	*.95*
1927	73	*.30*	*.30*	*.70*	*.54*	*.57*	*.51*
1929	61						*.79*
				Leaf Rust			
1927	73	*.62*	*.47*	*.39*	*.56*	*.41*	*.80*
1928	70						*.50*
1929	61	*.41*	*.40*	*.37*	*.71*	*.65*	*.66*

*Statistically significant correlation coefficients italicized.

The average of the inter-station correlation coefficients for grain plumpness are higher than those for yield. The same is true of the inter-annual correlation coefficients. The inter-relationships between plumpness at Waseca, Crookston, and Morris were significantly higher than the comparisons including University Farm, due to a lack of rust infection at University Farm. Inter-station date of heading correlations were highly significant, as might be expected.

The correlation coefficients for stem rust were significant in every instance but one and above .50 in 11 of the 14 comparisons. Stem rust reaction was quite constant at the different stations. The wheats grown in these experiments had been tested previously for resistance to a large number of physiological forms of stem rust in the rust nursery at University Farm and the susceptible material was eliminated. Because of this previous trial it would be expected that the

strains would react to stem rust in a similar manner at all stations as the strains probably are resistant under field conditions to practically all physiologic forms prevalent in the spring wheat area.

All of the inter-station correlation coefficients for leaf rust were statistically significant.

In Table 7 inter-station correlation coefficients for durum wheats are given.

TABLE 7.—*Inter-station correlations between characters of durum wheat strains and varieties.*

Year	No. of strains	Stations compared*: University Farm and Waseca	University Farm and Crookston	University Farm and Morris	Waseca and Crookston	Waseca and Morris	Crookston and Morris
				Yield			
1927	28	−.17	.16	−.06	*−.47*	−.06	.07
1928	42	*.55*	.25	.15	.25	.13	.20
1929	18	*.47*	*.49*	.32	.36	*.57*	*.57*
	Average	*.33*	*.27*	.12	.04	.17	*.24*
				Plumpness			
1927	28	.08	.10	.10	.24	.06	−.16
1928	42	.21	*.34*	*.40*	*.47*	*.43*	*.68*
1929	18	*.58*	*.54*	.36	*.51*	*.49*	*.73*
	Average	.25	*.31*	*.30*	*.41*	*.33*	*.40*
				Heading Date			
1927	28	*.77*	*.71*		*.72*		
1928	42	*.43*	*.81*	*.71*	*.36*	*.31*	*.61*
1929	18	*.83*	*.80*		*.88*		
	Average	*.65*	*.78*		*.62*		

*Statistically significant correlation coefficients italicized.

Yields of durum wheat at University Farm and Waseca were more highly correlated, on the average, than for any other combination of stations. The yield differences between any combination of stations are not statistically significant. Yields of durum wheat at University Farm and Morris have not been significantly correlated.

The inter-station correlations for plumpness are higher in general than those for yield. None were as high as those for hard red spring wheats. The inter-station correlation coefficients for heading date were high, as in the previous study.

In Table 8 are given inter-station correlation coefficients for oat strains grown at University Farm, Waseca, Crookston, and Morris covering a period of three years.

The material consisted of strains which were differentiated rather widely for period of maturity. Here also yields are more similar, on the average, at University Farm and Waseca than at University

Farm and Crookston or Morris, although the difference is not statistically significant. Waseca yields were more analagous to those at Morris than to those at Crookston. All of the average inter-station correlation coefficients for oats are statistically significant, a condition not found in the wheat comparisons.

TABLE 8.—*Inter-station correlations between characters of the oat strains and varieties.*

Year	No. of strains	Stations compared*					
		University Farm and			Waseca and		Crookston and Morris
		Waseca	Crookston	Morris	Crookston	Morris	
		Yield					
1927†	38	*.61*	*.66*	.30	*.58*	*.81*	*.38*
1928	31	.34	—.18	—.12	.27	.35	.19
1929	29	*.37*	*.43*	*.37*	*.42*	*.27*	*.45*
Average		*.46*	*.37*	*.27*	*.44*	*.56*	*.34*
		Plumpness					
1927†	38	*.71*	*.63*	*.54*	*.61*	*.63*	*.32*
1928	31	*.38*	—.05	.06	.34	.09	.28
1929	29	—.13	.09	—.03	.10	.02	.14
Average		*.41*	*.29*	*.24*	*.40*	*.31*	*.26*
		Heading Date					
1927†	38	*.85*	*.78*		*.84*		
1928	31	*.87*	*.73*		*.79*		
1929	29	*.80*	*.89*	*.49*	*.92*	*.44*	*.47*
		Crown Rust					
1927†	38	*.62*	*.47*		*.56*		
1929	29	*.47*		*.54*		*.43*	

*Statistically significant correlation coefficients italicized.
†Reported previously by Immer and Stevenson (5).

Inter-station correlation coefficients for plumpness in oats are smaller in every case than those for yield, also at variance with the results for wheat. This is very likely a result of greater variability in wheat which results from stem rust. The date of heading comparisons show a high similarity of response.

All inter-station correlation coefficients between crown rust reaction at different stations are significant and .43 or above. Again it seems that reaction to rust (crown rust in this case) is quite similar regardless of the station in Minnesota at which these notes were taken.

SUMMARY

1. Plumpness of grain was found to be closely associated with yielding ability. The relationship between date of heading and yield varied with the crop, the year, and the station.

2. Stem and leaf rust reaction were negatively correlated with yield in hard red spring wheat in most of the comparisons made. Crown rust infection was found to be negatively associated with yield in oats.

3. Inter-annual studies indicated that the strains tested for several years sometimes yielded in a comparable manner in successive years and sometimes the yields one year showed little or no relationship to the yields in the succeeding year.

4. Reaction to stem and leaf rust in wheat and crown rust in oats was quite constant from year to year and from station to station.

5. Plumpness of grain, disease reaction, and date of heading were correlated significantly at the various stations.

6. Yields at University Farm were correlated more closely with those at Waseca than with yields of the same strains grown at Crookston or Morris; although the differences were seldom statistically significant. Yields at Morris were correlated to a similar extent with those at Waseca and at Crookston. It is apparent that environmental conditions at the different stations were a direct cause.

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EFFECT OF DEPTH OF SEEDING ON THE OCCURRENCE OF COVERED AND LOOSE SMUTS IN WINTER BARLEY[1]

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Covered smut (*Ustilago hordei* (Pers.) Kell. and Sw.) and loose smut (*Ustilago nuda* (Jens.) Kell. and Sw.) are the most common plant diseases affecting fall-sown barley. Their importance as measured by reduced grain yield can only be estimated. However, in a 4-year experiment at the Arlington Experiment Farm, Rosslyn, Va., the reduced grain yield of two smut-susceptible varieties grown from untreated seed as compared to the yield of the two varieties from treated seed was approximately equal to the combined percentages of the loose and covered smuts present in the untreated plats.

The breeding of smut-resistant varieties of barley has been handicapped by lack of a satisfactory technic for obtaining infection. Investigators also have reported unsatisfactory results in varietal tests for covered smut, as infection has been either too low or too variable to be conclusive. Therefore, any factors which influence infection of the barley plant by smut are important.

The seedbed for the varietal experiments with winter barley at the Arlington Experiment Farm in 1922 was prepared in such a manner that a back furrow ran across the middle of each plat. It was observed that in this back-furrow area the barley plants were heavily infected with both smuts, whereas the remainder of the plat contained few smutty plants. Similar non-uniform distribution of infected plants was commonly observed when taking smut records on seed treatment experiments. As a result of these observations depth-of-seeding experiments were begun in 1924, the results of which are reported in this paper.

Tisdale[3] reports unsatisfactory results in obtaining infection of barley with covered smut when the seed was smutted at sowing.

Mackie[4] states, "Experiments in California have for three years failed in an attempt to create heavy smut attacks by artificially inoculating barley seed." He further states that low lying river or lake bottom lands usually show the most barley smut.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication November 3, 1930.

[2]Associate Agronomist and formerly Assistant Pathologist, respectively.

[3]STAKMAN, E. C. Diseases of cereal and forage crops in the United States in 1921. U. S. D. A. Bur. Plant Indus., Plant Dis. Bul. Sup., 21:139–254. 1922. (See page 208.)

[4]*Op. cit.*, page 209.

Faris[5] found that on Hannchen barley the race of covered smut he used produced high percentages of infection over a wide range in temperature. He says, "The amount of infection is influenced unfavorably somewhat by the relatively low soil temperatures at the time of planting spring barley, and this may account for the fact that covered smut is much less a problem in connection with spring than with winter barley."

Seiffert,[6] in a study of varietal susceptibility to artificial inoculation with loose smut, has found that shallow seeding appears to minimize the tendency to infection.

MATERIALS AND METHODS

Previous to 1929, all barley seed sown in these experiments came from practically smut-free plats. The seed for the 1929 experiment was taken from the crop produced on one of the 3-inch depth-of-seeding plats of the 1928 experiments. This seed was naturally infected with both loose and covered smuts to a comparatively high degree. The grain from a single plat of the previous season's crop of each variety supplied each year's seed, with the exception of that used in 1928 when the grain from two plats of Tennessee Winter (C. I. No. 3543) was necessary. In this latter instance, however, the same number of plats of each depth of seeding was sown from each of these two seed lots. No artificially inoculated seed was used in the experiments. Inoculation through natural infection in the field and in harvesting and threshing apparently is the general rule at the Arington Experiment Farm.

Plats 1/80th acre in size were used in all years. The varieties grown were Tennessee Winter (C. I. No. 3543), Tennessee Winter (C. I. No. 3546), Wisconsin Winter (C. I. No. 2159), Esaw (C. I. No. 4869), a selection from Nakano Wase, and Beardless (C. I. No. 2746). The Tennessee Winter strains and Wisconsin Winter possess a relatively high degree of winterhardiness. Esaw is an excellent yielding variety and highly resistant to the covered smut occurring at Arlington Farm. Beardless is a low yielding variety resistant to local forms of covered smut.

Plats were sown with a 12-spout, single-disk Van Brunt drill. Each half of the drill was adjusted so that two plats of five rows each, and each at a different depth, were sown at a trip across the field.

[5] FARIS, J. A. Factors influencing infection of *Hordeum sativum* by *Ustilago hordei*. Amer. Jour. Bot., 11:189–214, illus. 1924. (See page 211.)

[6] SEIFFERT, J. Künstliche Blüteninfektionen zur Untersuchung der empfänglichkeit verschiedener Gerstensorten für *Ustilago hordei nuda* und der Einfluss äusserer bedingungen auf die höhe des Brandprozentes. Kühn-Arch., 12:423–515. 1926. Also, abs. in Rev. Appl. Mycol., 6:412. 1927.

When more than one plat of a variety was sown at each depth on the same date and parcel of ground, the drill was turned and the side which seeded at the shallower depth on the first trip was set to seed the deeper on the return, and *vice versa*. This procedure should have eliminated any possible chance of differences in smut infection in the seed lots.

Smut percentages were obtained by counting the heads in definite areas of the rows selected at random. The number of areas used depended on the uniformity of the infection. The number of normal heads, and the number in each area, affected with covered and loose smuts were counted. Each year considerable variation was found in the percentages of the two smuts in the different areas of the same plat (Tables 1 and 2). This variability may be due in part to the difficulty of maintaining the depth at which the drill is set to seed. Crop residues in the soil and non-uniformity in the compactness of the seedbed also tend to produce irregularities in the seeding depth. The contour of the land likewise influences the depth of seeding.

EXPERIMENTAL DATA

RESULTS IN 1925

In the first depth-of-seeding experiments with winter barley in 1924, one plat of Tennessee Winter (C. I. No. 3543) was sown at a depth of ½ inch and a second at 3 inches. No attempt was made to differentiate between covered and loose smut in this preliminary experiment. In the 3-inch plat there were 80 smutted heads and 920 healthy heads in the area counted, compared to 10 smutted heads and 822 healthy heads in the ½-inch plat. There was 8.0% of smut in the 3-inch plat and 1.2% in the ½-inch plat.

RESULTS IN 1926

In the fall of 1925, two 1/80th-acre plats of Tennessee Winter (C. I. No. 3543) were sown at a depth of ½ inch and two at 3 inches. The plats of each depth of seeding were alternated. Six areas were counted in each plat to determine the percentage of each smut. The data from each area for all four plats are given in Table 1. The average percentage of the two smuts at each depth of seeding for the two plats shows satisfactory agreement. In plat 1, sown at 3 inches, there was 8.4% of covered smut and 3.8% of loose smut, while in duplicate plat 3, sown at the same depth, the percentages of covered and loose smuts were 9.7 and 3.2, respectively. Plat 2, sown at ½ inch, contained but 2.1% of covered smut and 1.0% of loose smut, while duplicate plat 4 showed 3.0% of covered smut and 1.1% of loose

smut. The two-plat averages for 1926 were 8.9% of covered smut and 3.5% of loose smut from the 3-inch depth of seeding and 2.5% of covered smut and 1.1% of loose smut from the ½-inch depth of seeding.

TABLE 1.—*Number of normal heads and of heads affected with covered and loose smuts and the percentages of each smut in four 1/80th-acre plats of Tennessee Winter barley sown at 3-inch and ½-inch depths at the Arlington Experiment Farm, 1926.*

Number of heads					
3-inch depth			½-inch depth		
Normal	Covered smut	Loose smut	Normal	Covered smut	Loose smut
316	6	5	333	6	2
130	34	4	290	4	3
257	12	10	460	7	2
175	20	13	309	15	7
199	21	7	362	13	3
270	36	19	391	2	5
Totals, 1,347	129	58	2,145	47	22
Percentages	8.4	3.8	—	2.1	1.0
129	29	4	227	3	0
179	28	12	292	6	9
128	5	5	345	12	9
120	10	2	248	2	1
122	6	3	291	25	1
200	20	6	294	5	0
Totals, 878	98	32	1,697	53	20
Percentages	9.7	3.2	—	3.0	1.1
2-plat av., %	8.9	3.5	—	2.5	1.1

RESULTS IN 1927

On October 12, 1926, two adjacent plats of Tennessee Winter (C. I. No. 3543) were sown, one at a depth of 3 inches and the other at a depth of ½ inch. Data were taken from 12 areas in each plat (Table 2). The plat sown at 3 inches contained 9.4% of covered smut and 7.7% of loose smut, compared to 2.4% of covered smut and 0.8% of loose smut in the ½-inch plat. The effect of depth of seeding on the occurrence of loose smut is particularly noticeable.

RESULTS IN 1928

A more thorough test of the effect of depth of seeding on the occurrence of the barley smuts was made in 1928. Five varieties of barley were sown. Tennessee Winter (C. I. No. 3543) was sown on four dates and on three different soil types. Beardless (C. I. 2746) and Tennessee Winter (C. I. No. 3546), an earlier maturing selection

from the old Tennessee Winter (C. I. No. 257), were sown on both a light and a heavy soil. Wisconsin Winter and Esaw were sown on two dates and on two types of soil.

TABLE 2.—*Number of normal heads and of heads affected with covered and loose smuts and the percentage of each smut in two adjacent 1/80th-acre plats of Tennessee Winter barley sown at 3-inch and ½-inch depths at the Arlington Experiment Farm, 1927.*

Number of heads					
3-inch depth			½-inch depth		
Normal	Covered smut	Loose smut	Normal	Covered smut	Loose smut
135	11	11	78	0	0
150	3	7	144	2	0
215	74	45	183	3	2
191	15	23	227	10	2
59	9	9	127	2	0
94	4	3	52	4	0
97	11	11	195	5	0
108	7	2	191	4	2
122	16	16	142	1	3
100	17	11	114	3	4
127	6	9	143	4	2
188	6	0	119	4	0
Totals, 1,586	179	147	1,715	42	15
Percentages	9.4	7.7	—	2.4	0.8

The average data for each plat are presented in Table 3. For each seeding date and soil type, the 3-inch depth of seeding produced decidedly more of both smuts than the ½-inch depth in both the Tennessee Winter strains and in Wisconsin Winter. No measurable percentage of covered smut occurred in Beardless or Esaw. Beardless showed more loose smut at the 3-inch depth than at the ½-inch depth in both comparisons, but the percentages of infection were too low to be definitely significant. The differences in loose smut infection in Esaw also were inconclusive.

No conclusions are justifiable as to the effect of dates of seeding or types of soil on the percentages of the smuts. It is interesting to note that a comparatively high percentage of covered smut occurred in Tennessee Winter (C. I. No. 3543) grown on the light soil from the ½-inch seeding on October 15 and October 22. The October 15 seeding at the ½-inch depth also showed 7.5% of loose smut, but in the October 22 seeding only 1.0% of the heads were infected with loose smut.

The averages of all seedings of Tennessee Winter (C. I. No. 3543) show 17.8% of covered smut and 8.8% of loose smut from the 3-inch seeding, as compared to 6.6% of covered smut and 4.1% of loose

TABLE 3.—*Number of normal heads and of heads affected with covered and loose smuts and the percentages of each smut in 1/80th-acre plats of five varieties of winter barley sown at 3-inch and ½-inch depths on different dates and on different soil types at the Arlington Experiment Farm, 1928.*

C. I. No.	Date sown	Soil texture	Seeding depth: 3 inches, Number of heads: Normal	Covered smut	Loose smut	Percentage of: Covered smut	Loose smut	½ inch, Number of heads: Normal	Covered smut	Loose smut	Percentage of: Covered smut	Loose smut
						Tennessee Winter						
3543	Oct. 7	Heavy	2,012	298	213	11.8	8.4	2,252	102	99	4.2	4.0
3543	Oct. 15	Light	1,202	333	229	18.9	13.0	1,110	127	100	9.5	7.5
3543	Oct. 17	Very light	360	29	21	7.1	5.1	242	2	10	0.8	3.9
3543	Oct. 22	Light	662	365	44	34.0	4.1	1,318	134	15	9.1	1.0
3546	Oct. 22	Light	443	27	22	5.5	4.5	429	0	0	0	0
3546	Oct. 22	Heavy	300	4	2	1.3	0.7	515	0	2	0	0.4
						Wisconsin Winter						
2159	Oct. 15	Light	3,730	229	152	5.6	3.7	4,613	87	62	1.8	1.3
2159	Oct. 22	Light	599	24	12	3.8	1.9	841	4	2	0.5	0.2
2159	Oct. 22	Very heavy	375	10	11	2.5	2.8	479	0	5	0	1.0
						Beardless						
2746	Oct. 22	Light	633	0	17	0	2.6	670	0	10	0	1.5
2746	Oct. 22	Very heavy	596	0	24	0	3.9	534	0	4	0	0.7
						Esaw						
4869	Oct. 15	Light	3,584	1	80	Trace	2.2	4,304	0	77	0	1.8
4869	Oct. 22	Light	688	0	4	0	0.6	951	0	5	0	0.5
4869	Oct. 22	Very heavy	5,003	0	27	0	0.5	6,848	0	22	0	0.3

smut at the ½-inch depth. Tennessee Winter (C. I. No. 3546) had 3.9% of covered smut and 3.0% of loose smut at the 3-inch seeding depth, and no covered smut and only 0.2% of loose smut at the ½-inch depth. Wisconsin Winter averaged 5.1% of covered smut and 3.4% of loose smut at the 3-inch depth compared to 1.5% of covered smut and 1.1% of loose smut at the ½-inch depth.

RESULTS IN 1929

The effect of depth of seeding on the occurrence of covered and loose smuts was very significant in 1929 in the varieties Wisconsin Winter and Tennessee Winter (C. I. No. 3543). Esaw showed no covered smut and no real difference in loose smut percentages.

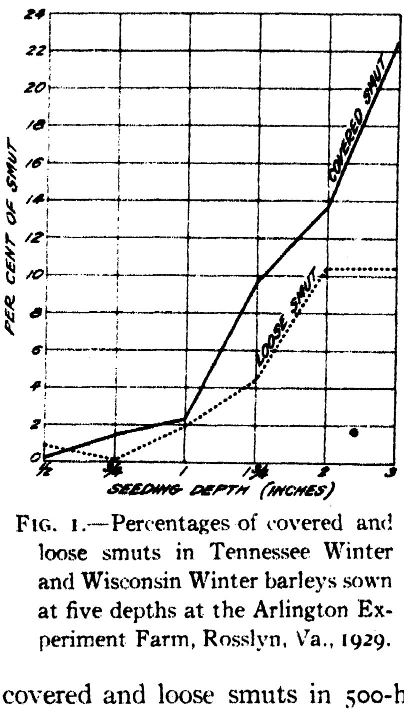

FIG. 1.—Percentages of covered and loose smuts in Tennessee Winter and Wisconsin Winter barleys sown at five depths at the Arlington Experiment Farm, Rosslyn, Va., 1929.

Wisconsin Winter was sown at each of five depths, *viz.*, ½ inch, ¾ inch, 1 inch, 2 inches, and 3 inches. Tennessee Winter was sown at three depths, *viz.*, ½ inch, 1¾ inches, and 3 inches. All varieties were sown on the same date. The data in Table 4 represent the average counts for each 1/80th-acre plat. Fig. 1 shows graphically the combined percentages of each smut at each seeding depth for the two varieties, Tennessee Winter and Wisconsin Winter. Fig. 2 shows the number of normal heads and heads affected with covered and loose smuts in 500-head samples of Wisconsin Winter from each of four seeding depths. The percentages of covered smut increased progressively with seeding depth. At ½ inch there was less than 0.3% of covered smut, while at the 3-inch depth 22.4% of covered smut was present.

The percentages of infection of loose smut show a similar trend to those of the covered smut, though less pronounced. No difference of significance is shown in the percentages of loose smut in the ½-inch depth as compared to the ¾-inch depth or in the comparison of the 2-inch depth with the 3-inch depth.

TABLE 4.—*Number of normal heads and of heads affected with covered and loose smuts and the percentage of each smut in 1/80th-acre plats of three varieties of winter barley sown at different depths at the Arlington Experiment Farm, 1929.*

Seeding depth, inches	Wisconsin Winter					Tennessee Winter					Esaw				
	Number of heads			Percentage of		Number of heads			Percentage of		Number of heads			Percentage of	
	Normal	Covered smut	Loose smut	Covered smut	Loose smut	Normal	Covered smut	Loose smut	Covered smut	Loose smut	Normal	Covered smut	Loose smut	Covered smut	Loose smut
½	1,270	4	35	0.3	2.7	2,003	3	1	0.2	0.2	—	—	—	—	—
	—	—	—	—	—	1,186	2	4	—	—	—	—	—	—	—
¾	1,365	19	1	1.4	0.1	—	—	—	—	—	2,384	0	146	0	5.8
	2,245	88	77	—	—	—	—	—	—	—	—	—	—	—	—
1	1,506	37	16	2.3	1.9	—	—	—	—	—	—	—	—	—	—
	2,674	26	35	—	—	—	—	—	—	—	—	—	—	—	—
1¾	—	—	—	—	—	2,616	413	210	9.6	4.4	—	—	—	—	—
	—	—	—	—	—	2,176	120	36	—	—	—	—	—	—	—
2	1,346	241	184	13.6	10.4	—	—	—	—	—	—	—	—	—	—
3	646	115	20	21.4	12.3	1,348	534	149	23.0	8.9	—	—	—	—	—
	994	415	283	—	—	1,063	281	167	—	—	1,642	0	100	0	5.7

DISCUSSION

The depth of seeding winter barley was found to play an important rôle in the percentages of infection of both covered and loose smuts in Tennessee Winter and Wisconsin Winter. Fig. 3 shows graphically the 4-year average percentages of each smut present in Tennessee Winter (C. I. No. 3543) grown from the ½-inch and 3-inch seedings. In 1926, there was approximately 3.6 times as much covered smut and 3.2 times as much loose smut in the 3-inch sowings as in the ½ inch; in 1927, 3.9 and 9.6, respectively; in 1928, 2.7 and 2.1, respectively;

FIG. 2.—Number of normal heads and heads affected with covered and loose smuts in 500-head samples of Wisconsin Winter barley sown at four seeding depths on the Arlington Experiment Farm, Rosslyn, Va. A, ½-inch depth; B, 1-inch depth; C, 2-inch depth; D, 3-inch depth.

and in 1929, 115.0 and 44.5, respectively. The high percentage of smut resulting from the 3-inch seeding in 1929 no doubt was partly due to the use of seed from plats showing heavy infection in 1928. The low infections of both smuts in the ½-inch seeding, however, must be attributed to environment. The seedbed was unusually dry and germination from the ½-inch seeding was poor. The available data are not sufficient to explain the relationship between climatic and soil factors and infection. Further study is being made of this subject.

The data obtained in 1929 show that in this year the crops from the ½-, ¾-, and 1-inch depths of sowing were all low in infection, while in

the 1¾-, 2-, and 3-inch sowings the infections of both smuts were much increased.

Faris[7], in presenting a study of the effect of moisture, temperature, soil-acidity, and physiological specialization on infection by the covered-smut fungus, states, "The final amount of disease appearing is due to the interaction of a multitude of factors, only a few of which have been singled out for this study." The complex responsible for the effect of depth of seeding on the infection of barley with both covered and loose smuts must be considered deserving of further study.

The practical value of seeding at a shallow depth to reduce the smuts of winter barley is dependent on the effect that shallow seeding has on grain yield. The comparative yields of fall-sown barley when sown at different depths are being studied. The proper depth of seeding will perhaps depend upon seasonal soil moisture and the tendency of the crop when sown at different depths to be more or less affected by heaving. Except for the 1929 crop, in the past 5 years excellent stands were obtained from ½-inch seeding, and with no apparent increased injury from heaving.

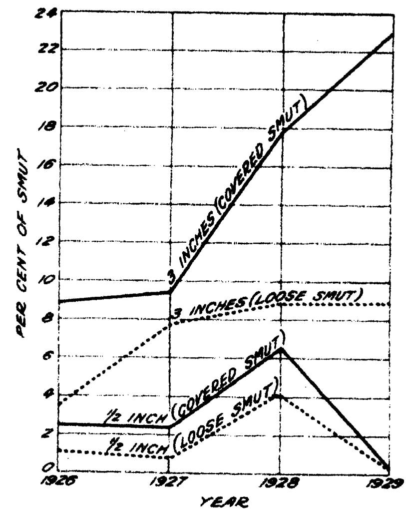

FIG. 3.—Annual percentages of covered and loose smuts in Tennessee Winter barley sown at depths of ½ inch and 3 inches on the Arlington Experiment Farm, Rosslyn, Va., for the 4-year period from 1926 to 1929, inclusive.

CONCLUSIONS

In the 4-year experiment, 2.7 to 115 times as much covered smut was present in Tennessee Winter barley sown at 3 inches as in the same variety sown at ½ inch. Loose smut was from 2.1 to 44.5 times greater in amount in the 3-inch seeding as compared to the ½-inch. Wisconsin Winter gave results similar to Tennessee Winter in a 2-year experiment. Esaw and Beardless, varieties resistant to the local covered smut, showed no significant difference in loose-smut infection from variation in seeding depth.

[7]*Op. cit.*, page 210.

THE ABSORPTION OF AMMONIUM AND NITRATE NITROGEN BY VARIOUS PLANTS AT DIFFERENT STAGES OF GROWTH[1]

JAMES A. NAFTEL[2]

A knowledge of the absorption of ammonium and nitrate ions by plants is of fundamental importance in a study of the use of nitrogenous fertilizers. This has been too generally overlooked by agronomists and soil chemists. Moreover, little consideration has been given to the possibility of the actual absorption of nitrogen in the ammonium form. This is true even though more work has been done on nitrogen fertilization than on any other phase of soil fertility. It has generally been conceded that nitrogen applied in the form of ammonium salts or in organic forms must be oxidized to the nitrate form before it can become available to plants. The rice plant is an exception to this general assumption.

It has been observed that plants fertilized with both NH_4- and NO_3-N make more rapid growth in their early stages than those receiving NO_3 alone. Hutchinson and Miller (1)[3] gave a review of the early work on absorption of NH_4- and NO_3-N and concluded that most plants can utilize either form of nitrogen. Some plants grew better throughout their entire growth period when the nitrogen was supplied as NO_3. The best growth was generally obtained, however, when both forms of nitrogen were present. Jones and Skinner (2) found that soybeans and corn absorbed more NH_4- than NO_3-N in the early stages of growth.

No work has been found wherein plants have been compared as to the relative absorption of NH_4- and NO_3-N and the corresponding growth resulting therefrom, either in nutrient solutions of varying concentrations of each form of nitrogen, or in solutions of only one form of nitrogen. Moreover, no work has been found wherein nitrogen absorption has been studied in solution cultures with controlled H-ion concentrations. It has previously been shown by Jones and Shive (3) that the reaction of nutrient solutions with growing plants is

[1]Contribution from the Department of Agronomy, Alabama Agricultural Experiment Station, Auburn, Ala. A thesis presented in partial fulfillment of the requirements of the degree of master of science at the Alabama Polytechnic Institute. Published with the approval of the Director of the Alabama Experiment Station. Received for publication November 6, 1930.

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[3]Reference by number is to "Literature Cited," p. 157.

determined by the differential absorption of ions. That is, when NH_4-N is absorbed from solutions in which $(NH_4)_2SO_4$ is the source of nitrogen, the reaction of the culture solution becomes more acid, whereas the reverse is true with the absorption of NO_3-N from $Ca(NO_3)_2$.

OBJECTS

The objects of this investigation were: (a) To determine whether or not plants actually absorb NH_4-N; (b) to determine the relative absorption of NH_4- and NO_3-N by plants during the early stages of growth; (c) to determine the influence of NH_4-N, if absorbed, on the early growth of plants; (d) to study the influence of H-ion concentration on the relative absorption of NH_4- and NO_3-N; (e) to note the relative yields of cotton grown in soil with varying treatments of NH_4- and NO_3-N; and (f) to determine the relative amounts of NH_4- and NO_3-N present and the pH value of sap expressed from plants at different ages.

EXPERIMENTAL PROCEDURE

PLAN OF INVESTIGATION

The absorption of NH_4- and NO_3-N was studied by growing plants in nutrient solutions of known concentrations of each ion. The nutrient solutions used throughout this investigation were especially designed for the NH_4- and NO_3-N absorption studies. They are peculiarly interesting for these absorption studies, since the plants were grown in culture solutions containing (a) all NH_4-N, (b) all NO_3-N, (c) equal parts of NH_4- and NO_3-N, and (d) varying amounts of these ions. The total concentration of nitrogen was held constant at 80 p.p.m. in all of the solutions. The absorption and the growth of the seedlings were studied with the complete series of nutrient solutions. Cotton, wheat, and corn were investigated as to the relative absorption of the two forms of nitrogen and to the growth resulting from absorption in a series of solutions of varying concentrations of NH_4 and NO_3 ions.

The absorption of NH_4- and NO_3-N during the early stages of growth is of considerable physiological importance. It was indicated above that ammonium fertilizers caused marked responses in the early growth of plants. The work reported here was designed especially to note the ratio of NH_4-N to NO_3-N absorbed during the early stages. The absorption during the stages from the time the plants came up until they were five to eight weeks old was the most significant covered by this investigation.

The practical application of the results obtained was studied in soils both in the greenhouse and in field plats. Applications of NH_4- and NO_3-N were made and the presence of these ions in the soil was noted at different intervals of time. Nitrification, growth, and nitrogen content of plants at different stages were studied. An explanation of the observed absorption phenomena and results of growth obtained was attempted. Studies were made on the content of NH_4 and NO_3N present in the sap of seedlings at different ages.

CULTURE SOLUTIONS

All solutions were made from C. P. salts and nitrogen-free water. The composition of the nutrient solutions is shown in Table 1. All salts were made into stock solutions for convenience and ease in making up the various types of solutions.

TABLE 1.—*Concentration in mgms per liter of salts used in culture solutions.*

Solutions	$(NH_4)_2SO_4$			$Ca(NO_3).4H_2O$			KH_2PO_4			$MgSO_4.7H_2O$		
	Salt	N as NH_4	SO_4	Salt	N as NO_3	Ca	Salt	K	PO_4	Salt	Mg	SO_4
A	378	80.0	275	0	0	0	286	82	200	1,752	172	671
B	259	55.0	189	212	25	35	286	82	200	1,752	172	671
C	189	40.0	137	340	40	57	286	82	200	1,752	172	671
D	118	25.0	86	465	55	79	286	82	200	1,752	172	671
E	0	0	0	680	80	114	286	82	200	1,752	172	671

Solutions	NaCl			$CaCl_2.2H_2O$			$MnSO_4$		H_3BO_3	
	Salt	Na	Cl	Salt	Ca	Cl	Salt	Mn	Salt	B
A	6.0	2.36	3.34	418	114	200	3.75	1.1	2.5	0.44
B	6.0	2.36	3.34	291	79	140	3.75	1.1	2.5	0.44
C	6.0	2.36	3.34	209	57	100	3.75	1.1	2.5	0.44
D	6.0	2.36	3.34	129	35	62	3.75	1.1	2.5	0.44
E	6.0	2.36	3.34	0	0	0	3.75	1.1	2.5	0.44

The stock solutions were analyzed at different intervals to determine whether or not the concentration of N was changing. Neither nitrification nor denitrification occurred. Analyses were made on freshly prepared culture solutions and on the same solutions after periods of time to determine whether or not nitrification occurred, but nitrification did not occur in 48 to 72 hours. This shows that the cultures to which only NH_4-N was added never contained NO_3-N and that the solutions of all NO_3-N were never contaminated with NH_4-N.

Iron was added to the cultures in the form of ferric tartrate. A 0.5% stock solution was prepared by adding H_2SO_4 until all the salt

was in solution. Ten cc of this stock solution in 2 gallons of water gave a concentration of 1.25 p.p.m. of Fe. When the plants showed the need for iron (slightly chlorotic), ferric tartrate solution was prepared in the above proportion and the culture placed in it for 48 hours.

STARTING CULTURES

Uniform seed were planted in quartz sand, with culture dishes used as containers. When the plants had reached sufficient size to be removed, they were placed in the nutrient solutions.

The culture solutions were made from the stock solutions. A sufficient volume was always made to supply all cultures of a single type so that the cultures would be growing in solutions of exactly the same nitrogen concentrations. The solutions were renewed periodically, 48 to 72 hours, to prevent nitrification and to keep the N content more constant.

MEASURING THE ABSORPTION

Various periods of absorption were used throughout the investigation. The length of the period and amount of solution from which absorption was made depended on the number of plants, the age of the plants, and upon the specific experiment. The actual amount of absorption was obtained by difference from analysis of the culture solution and its control. This is the most accurate method since in actual practice the amounts of N calculated to be in the solutions and the actual amount added will vary slightly due to the large volumes.

YIELDS

The growth or yields were determined at the end of the experiments by obtaining the dry weights of the tops and roots. Individual plants were weighed separately and oven-dry weights were determined whenever possible.

METHOD OF ANALYSES

The absorption of nitrogen was determined by analyses of the culture solutions before and after the absorption periods. The reduction method by the use of Devarda's alloy was used. The NH_4-N was determined by distillation of the solution after it was made alkaline. The ability to determine accurately the nitrogen in both forms, when present together in a solution, was studied, and the results showed that the method was satisfactory.

NH_4-N in the soils was determined by the aeration method of Potter and Snyder (6). NO_3-N in the soil was determined by the

phenoldisulfonic acid method. The clear extract was obtained by the use of collodion bags, as described by Pierre and Parker (5). The pH values of the soil were determined colorimetrically.

RESULTS

Studies were made of the absorption of NH_4- and NO_3-N and of the growth response of cotton, corn, and wheat seedlings at different stages in a series of culture solutions of varying NH_4- and NO_3-N concentrations at different pH values. Each of the nutrient solutitions contained 80 p.p.m. nitrogen. Soil studies with NH_4- and NO_3-N were made in the greenhouse and in the field, and sand cultures were also studied. Since all of the experiments gave similar results, only data for the experiments with cotton are presented here.

ABSORPTION OF NH_4- AND NO_3-N AND GROWTH RESPONSE BY COTTON SEEDLINGS

Experiment 1

The absorption of NH_4- and NO_3-N and the growth of cotton seedlings from water cultures were determined in this experiment. There were three separate studies, namely, (a) five duplicate cultures in solution C; (b) five duplicate cultures in solutions A, B, C, D, and E; and (c) five duplicate cultures in solution C, two each at pH 3.5, 4.0, 5.0, 6.0, and 7.0. The seedlings of the cultures were from seed which came from one plant of Cook 1627 variety. Cultures were grown in 4-liter earthenware crocks, and the solutions were changed every 48 to 72 hours.

Experiment 1-a.—Uniform plants were transferred at weekly intervals to solutions A, B, C, D, and E or to a series of solutions of C at pH 3.5, 4.0, 5.0, 6.0, and 7.0 for absorption studies. In the early stages of growth six seedlings were used to the culture, and were placed in 500 cc of solution for a 48-hour absorption period. As the plants grew larger fewer plants were left in each culture, and absorption was studied from 1 liter for 24 hours. Data of absorption at weekly intervals are given in Table 2.

Experiment 1-b.—Absorption studies were made on two cultures each in solutions A, B, C, D, and E. The solutions were changed twice a week and the reaction of the solution was maintained between pH 5.0 and 6.5 by daily additions of 2N NaOH or 2N H_2SO_4. The nitrogen absorbed was measured at weekly intervals, beginning when the plants were one week old. Absorption data are shown in Table 3. Photographs at different stages of growth are shown in Figs. 1 to 4.

TABLE 2.—*Absorption of NH_4- and NO_3-N from solutions of varying concentrations of these ions, by uniform cotton cultures at different ages.*

Cotton 5-A solutions	N absorption in mgms					
	8 days, 7 plants, 48 hours			16 days, 7 plants, 48 hours		
	NH_4	NO_3	Total N	NH_4	NO_3	Total N
A	12.0	—	12.0	4.6	—	4.6
B	5.2	4.6	9.8	4.5	3.2	7.8
C	8.4	6.1	14.5	5.6	7.3	12.9
D	8.3	9.4	17.7	5.3	9.9	15.2
E	—	3.6	3.6	—	—	—

Cotton 5-A Solutions	N absorption in mgms					
	28 days, 4 plants, 24 hours			35 days, 4 plants, 24 hours		
	NH_4	NO_3	Total N	NH_4	NO_3	Total N
A	14.2	—	14.2	24.4	—	24.4
B	15.8	10.8	26.6	12.0	24.0	36.0
C	12.2	12.8	25.0	16.0	33.6	49.6
D	10.8	14.2	25.0	10.8	20.4	31.2
E	—	13.8	13.8	—	56.8	56.8

Experiment 1-c.—Two cultures were grown in solution C at pH 3.5, 4.0, 5.0, 6.0, and 7.0. The culture solutions were renewed at weekly intervals and the pH adjusted every 48 hours. Growth studies were made on this series, and harvest data are shown in Table 4. The plants were harvested at the age of 8 weeks.

Discussion of Experiment 1.—Data in Table 2 show that the 8-day-old plants removed 12.0 mgm of NH_4-N from the all-NH_4 solution A, and only 3.6 mgms NO_3-N from the all-NO_3 solution E. With equal parts NH_4- and NO_3-N (solution C), 8.4 mgms of NH_4-N and 6.1 mgms of NO_3-N were removed. When the plants were 35 days old there was much more NO_3 than NH_4-N removed.

At the 6 weeks' stage the plants were studied at different lengths of absorption periods. The culture solution contained 40 mgm each of NH_4- and NO_3-N. It is interesting to note that during 20 hours of absorption the cotton plants removed practically all the NO_3-N and not quite half of the NH_4-N, or 37.1 mgms of NO_3-N and 16.4 mgms of NH_4-N (average of two cultures). During 30 hours of absorption the NH_4-N removed increased to 32.4 mgms. Apparently the plants first absorbed the NO_3-N and then after it was exhausted absorbed the NH_4-N.

TABLE 3.—*Twenty-four-hour absorption of NH4- and NO3-N by cotton plants at different stages of growth in culture solutions of varying concentrations of these ions.*

Culture solution	Mgms N absorbed											
	1 week			2 weeks			3 weeks			4 weeks		
	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_4	NO_3	Total N
A	7.4	—	7.4	10.9	—	10.9	14.2	—	14.2	4.5	—	4.5
B	3.3	0.5	3.8	10.0	5.0	15.0	11.8	12.8	24.6	6.5	2.7	9.2
C	5.4	3.7	9.1	6.6	7.3	13.9	17.4	18.0	35.4	6.1	9.6	15.7
D	2.8	2.5	5.3	9.8	14.7	24.5	13.0	16.8	29.8	5.6	6.5	12.1
E	—	4.4	4.4	—	8.3	8.3	—	11.2	11.2	—	3.7	3.7
	5 weeks			6 weeks			8 weeks			9 weeks		
A	15.2	—	15.2	21.8	—	21.8	15.0	—	15.0	20.2	—	20.2
B	24.8	24.0	48.8	33.4	23.4	56.8	24.4	23.2	47.6	13.8	18.0	21.3
C	27.6	38.2	65.8	31.8	36.0	67.8	10.8	24.6	35.4	18.2	33.2	51.4
D	21.4	53.4	74.8	24.2	53.4	77.6	16.2	52.4	68.6	10.4	51.0	61.4
E	—	31.6	31.6	—	38.6	38.6	—	56.6	56.6	—	36.4	36.4
	10 weeks			11 weeks			12 weeks			13 weeks*		
A	14.8	—	14.8	5.6	—	5.6	11.2	—	11.2	6.2	—	6.2
B	11.2	7.6	18.8	19.6	8.0	27.6	1.2	29.0	25.2	3.6	4.0	7.6
C	11.6	34.2	45.8	24.0	28.0	52.0	10.6	12.2	22.8	5.0	10.4	15.4
D	16.8	49.0	65.8	17.0	52.8	69.8	15.2	28.8	44.0	8.4	35.2	43.6
E	—	57.8	57.8	—	77.8	77.8	—	77.8	77.8	—	45.0	45.0

*Eight-hour absorption period.

TABLE 4.—*Dry weights of cotton plants at 8 weeks' harvest.*

pH	Tops		Roots	
	Green weight in grams	Dry weight in grams	Green weight in grams	Dry weight in grams
4.0	26.1	7.0	15.1	1.8
5.0	45.1	9.6	23.1	2.3
6.0	92.2	19.4	30.3	4.0
7.0	88.0	18.0	36.0	4.4

The data of experiment 1-b show that NH_4-N is absorbed more rapidly in the early stages than NO_3-N. When the plants were 8 days old there were 7.4 mgms NH_4-N removed from solution A and 4.4 mgms NO_3-N from solution E. From solution C the cotton absorbed 5.4 mgms NH_4-N and 3.7 mgms NO_3-N. The relative absorption of NH_4- and NO_3-N was practically the same at 3 weeks, but at 5 weeks more NO_3-N was absorbed than NH_4-N. Considerable NH_4-N was used by the plants until the plants were 9 weeks old, when the amount absorbed decreased considerably.

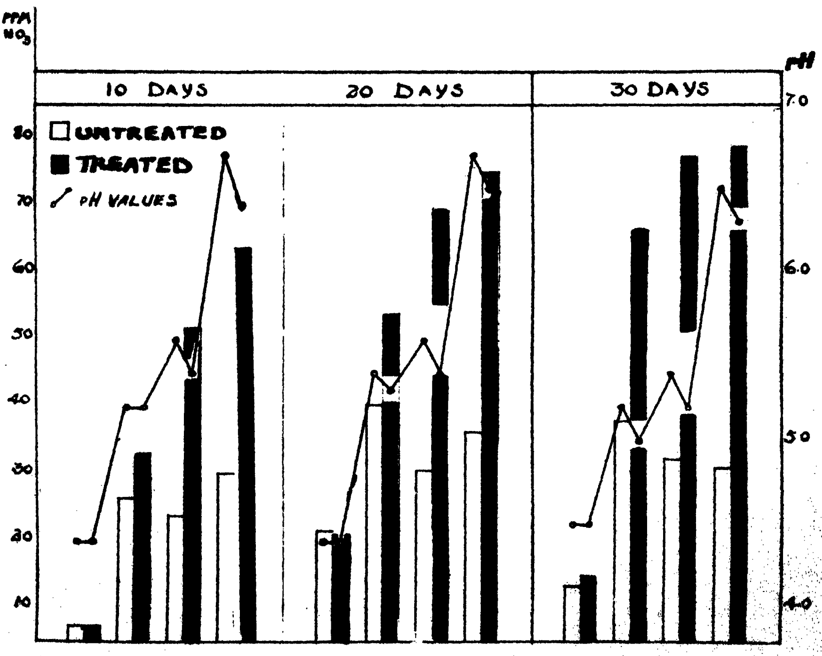

FIG. 1.—Cotton grown in solutions A, B, C, D, and E for 3 weeks.

The growth of the plants satisfactorily correlates with the relative amounts of nitrogen absorbed. At 3 weeks (Fig. 1) the seedlings in solution C were best. This relative growth continued until the

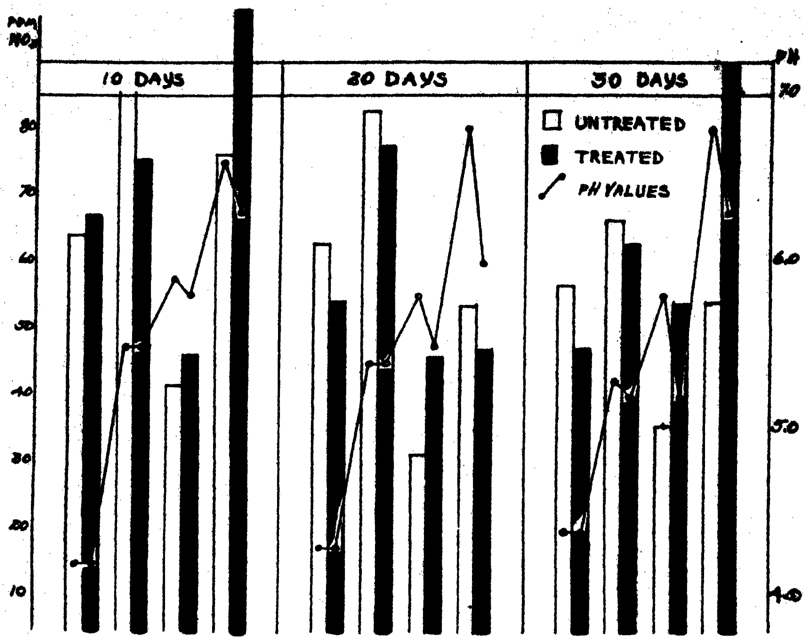

FIG. 2.—Cotton grown in solutions A, B, C, D, and E for 6 weeks.

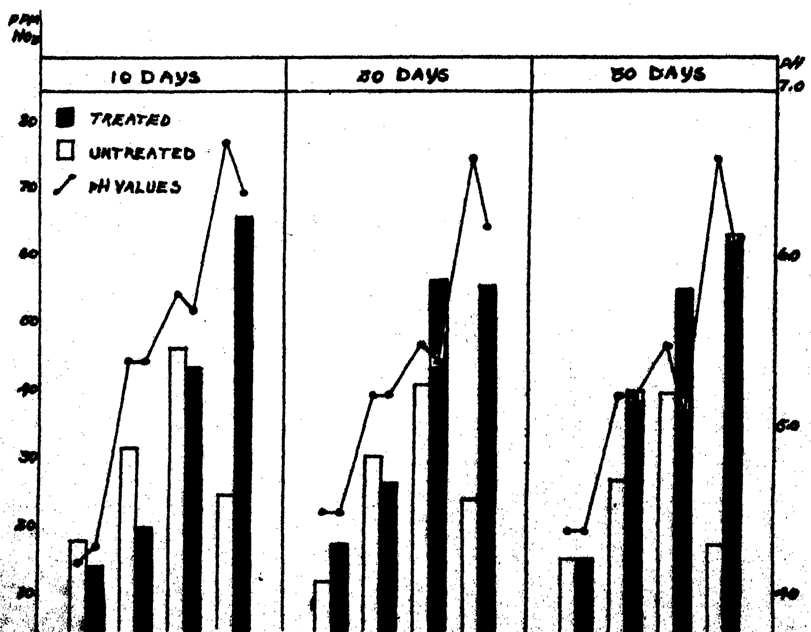

FIG. 3.—Cotton grown in solutions A, B, C, D, and E for 9 weeks.

plants were 6 weeks old, when plants in solution B were equal in growth to those in solution C, as shown in Fig. 2. At the age of 9 weeks plants in solutions C, D, and E were all similar in growth (Fig. 3). After the plants were 11 weeks old those in solution E had made larger growth than any other culture, as shown in Fig. 4.

There was considerable variation in the fruiting of cotton in the various nitrogen solutions. At 9 weeks old the number of bolls for the different culture solutions was as follows: A, all NH_4, 4; B, ⅔ NH_4 and ⅓ NO_3, 8; C, ½ NH_4 and ½ NO_3, 13; D, ⅓ NH_4 and ⅔ NO_3, 10; and in E, all NO_3, 0. At 13 weeks old the cotton plants contained the following number of bolls: A, 5; B, 6; C, 12; D, 13; and E, 7. It is interesting to note that fruiting was later on the plants grown in the solutions of all NO_3-N.

The effect of different H-ion concentrations on the absorption of NH_4– and NO_3-N was observed with cotton. More NH_4- than NO_3-N was removed when the plants were 1 week old. The NH_4-N removed was increased from 1.9 mgms at pH 3.5 to 7.8 mgms at pH 7.0. The NO_3-N absorbed was only slightly affected by varying the reaction of the solution. Since earlier preliminary growth of cotton in solution C was better at pH 4.0 than at either pH 5.0, 6.0, or 7.0, a low pH (3.5) was used in this study. At pH 3.5, however, the H-ion concentration was too high and the cultures died. The early growth of the other cultures at pH 4.0, 5.0, 6.0, and 7.0 was best at the lower pH values. As the plants grew older, the cultures at pH 6.0 made the best growth. Fig. 5 shows absorption of NH_4– and NO_3-N from pH 3.5 to pH 7.0.

Experiment 2

Cotton in sand cultures with nutrient solutions similar to those used in the water cultures was used in this study. Plants were grown in cylindrical glass percolators which were painted black and filled with 1,000 grams of washed quartz sand. Five seeds were planted in each percolator and after one week were thinned to three uniform seedlings per culture. Nutrient solutions were added to the cultures until 150 to 200 cc ran through. Repeated additions were made after the percolators were flushed with 500 cc of water and allowed to drain over night. Five duplicate cultures in solutions A, B, C, D, and E were used in this experiment.

The solutions were renewed twice a week and the growth noted by measuring the height of plants. Beginning when the plants were 5 weeks old, absorption of nitrogen was measured by adding a definite volume of each solution to the cultures for certain intervals and catching the leachings in flasks. After absorption had proceeded

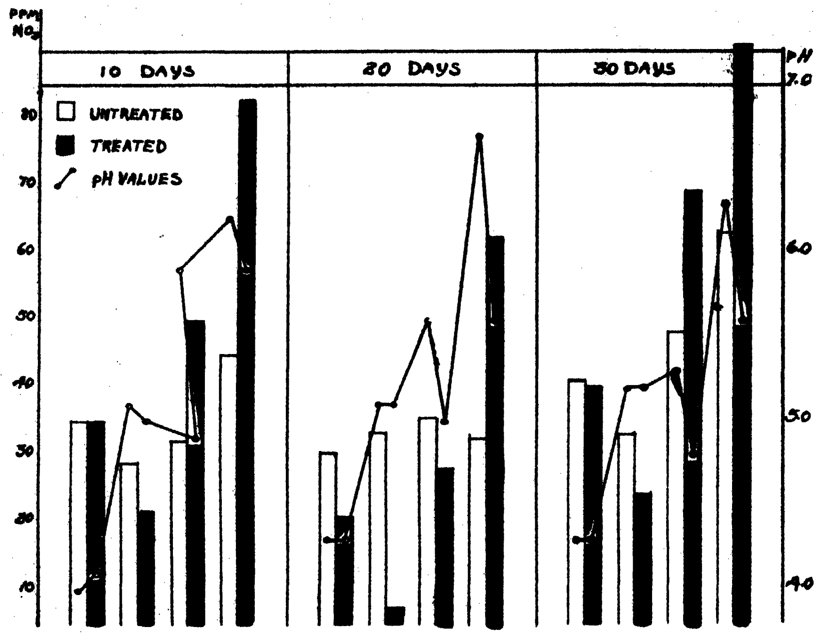

FIG. 4.—Cotton grown in solutions A, B, C, D, and E for 11 weeks.

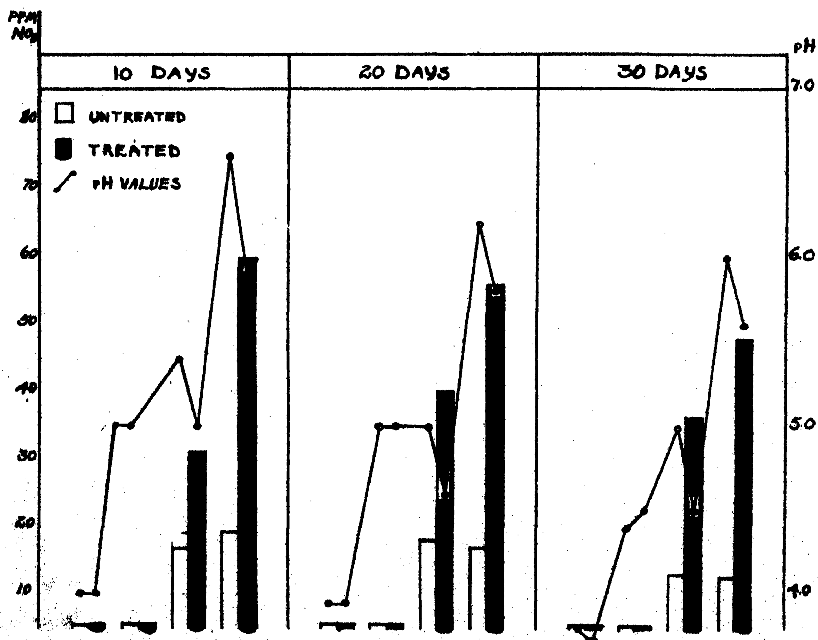

FIG. 5.—The absorption of NH_4- and NO_3-N at varying reactions.

through a definite interval of time, the culture was flushed with 400 cc of water and leachings caught in the same flask as used in the beginning. The leachings were made to definite volumes and aliquots analyzed for NH_4- and NO_3-N. The absorption data are given in Table 5.

TABLE 5.—*The absorption of NH_4- and NO_3-N by sand cultures of cotton at different ages from solutions of varying concentrations of these ions, average of duplicate cultures.*

Culture solution	Mgms of N absorbed								
	3 weeks			4 weeks			5 weeks		
	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_4	NO_3	Total N
A	7.2	—	7.2	10.0	—	10.0	5.1	—	5.1
B	6.2	2.4	8.6	10.1	4.8	14.9	6.9	3.0	10.0
C	4.9	4.2	9.1	10.5	11.0	21.5	5.1	4.2	9.3
D	2.9	5.3	8.3	6.8	13.9	20.7	3.2	6.0	9.2
E	—	9.0	9.0	—	19.9	19.9	—	8.7	8.7
	6 weeks			7 weeks			9 weeks		
A	6.2	—	6.2	7.3	—	7.3	13.2	—	13.2
B	7.5	1.7	9.2	5.3	2.1	7.4	14.0	7.2	21.2
C	5.2	5.2	10.4	4.8	8.3	13.1	12.2	18.8	31.0
D	3.6	7.2	10.8	2.9	8.5	11.4	17.0	34.6	51.6
E	—	10.3	10.3	—	8.4	8.4	—	44.4	44.4

Sand cultures were used in this investigation to check the work done in the water cultures. It was first planned to note only the growth of the cotton plants, but these cultures offered an excellent opportunity to measure the absorption of NH_4- and NO_3-N. These absorption studies came nearer duplicating conditions which might be expected to occur in soils than did water cultures.

The data in general show very similar results to those of the water cultures. Absorption studies were not made until the plants were 3 weeks old. At that time slightly more NH_4-N was removed than NO_3-N. This was true for all cultures except those receiving solutions A and E in which the smaller absorption of NH_4-N was probably due to the smaller plants in culture A. Slightly more NH_4-N was absorbed at 4 and 5 weeks than NO_3-N, except in the cultures mentioned above. When the plants were 6 and 7 weeks old the absorption of NO_3-N had surpassed that of NH_4-N. This relationship continued throughout the remainder of the investigation.

The growth of the plants was practically the same for all the cultures for the first 2 week's growth. When the plants were 3 to 4

weeks old the cultures of solutions C and D were considerably larger than those of B and E, and the latter larger than A. This growth relationship continued until the plants were 7 to 8 weeks old when the cultures of solution E (all NO_3) had made growth as large as cultures C and D. The plants in cultures C, D, and E made growth about equal during the remainder of the growth period.

Soil studies in the greenhouse and field with one crop of cotton gave results comparable with those from these solution cultures.

NITROGEN CONTENT OF SAP FROM COTTON SEEDLINGS

Cotton seedlings were grown for 3, 5, and 8 weeks in solution C and the sap of these plants was analyzed for NH_4- and NO_3-N at these stages of growth. The plants were harvested at the different periods and immediately placed in storage at 15° to 20° F. The roots and tops were separated and analyzed separately. The sap was expressed from the plants by means of a screw press and placed in well-stoppered flasks in cold storage until analyses were made. NH_4- and NO_3-N content of the sap was determined by the distillation reduction method. Nitrites were avoided by use of aspartic acid as suggested by Stroud (8). The pH value was determined by means of the quinhydrone electrode.

The content of NH_4-N was considerably lower than the NO_3-N in the sap from plants 3 weeks old. Sap from the tops contained 6.8 mgms NH_4-N and 32.0 mgms NO_3-N, while that from the roots contained 16.6 mgms NH_4-N and 11.0 mgms NO_3-N. At 5 weeks the NO_3-N content had been considerably reduced, the tops containing 3.6 mgms NH_4-N and 7.5 mgms NO_3-N. At 8 weeks the NO_3-N content of the sap had been reduced below the NH_4-N content; sap from the tops contained 5.8 mgms NH_4-N and 4.0 mgms NO_3-N. The NH_4-N in the roots was 12.4 mgms and the NO_3-N determination was lost.

This study indicates that both forms of nitrogen are utilized or removed by cotton plants at different stages of growth. Plants at 3 weeks growth do not utilize the NO_3 present in the sap but remove practically all of the NH_4. The previous absorption studies have shown that large amounts of both NH_4- and NO_3-N are absorbed. Evidently at this stage the NO_3-N tends to accumulate. The plants at 5 weeks utilize both the NH_4- and NO_3-N. At 8 weeks the NH_4-N was slightly higher than the NO_3-N content, indicating that the NO_3-N was removed more rapidly from the sap than the NH_4-N.

DISCUSSION

Absorption of both NH_4- and NO_3-N by seedlings occurs in appreciable amounts throughout all stages of the plants investigated. The higher absorption of the NH_4 ion in the early stages of the plants indicates more rapid utilization of this ion than the NO_3 ion. The early growth of seedlings is largest where NH_4- and NO_3-N are present in equal amounts in the solutions used. It might be expected that the largest early growth would be obtained in solution B, 2/3 NH_4-N and 1/3 NO_3-N, since this solution supplied the highest NH_4 in combination with NO_3 and approximated the ratio of NH_4- to NO_3-N absorbed. It is possible that the concentration of the NH_4 ion was too high in this solution for optimum growth of the plants. It is known that the NH_4 ion is toxic in high concentrations to both microorganisms and higher plants. Its toxicity is considerably influenced by the pH of the sap.

The growth of seedlings from the absorption of both NH_4 and NO_3 is greater than that from either ion alone. Fruiting is earlier and is increased by supplying both NH_4 and NO_3 ions. In most cases it was found that the plants growing in solution E, all NO_3, finally became larger than those in the other solutions. This is most likely due to the larger amount of NO_3-N which was supplied by this solution in the later stages when the plant was absorbing the highest amount of NO_3-N. This study is to be continued by supplying an equivalent amount of NO_3 to solutions C and D in addition to their normal amounts of NH_4-N. Another related study, which should prove of value, is to grow seedlings in solution C for 3 to 5 weeks and then transfer them to solution E and note whether or not they continue to make larger growth than those grown in solution E during the entire period.

The easily soluble nitrogen of the seed, at the time the sprouts are produced, is present practically entirely in the NH_4 form. This is true also of the sap obtained from the sprouts. The cotton seed contained eight times as much NH_4- as NO_3-N. The expressed sap from the cotton sprouts contained 1,530 and 240 p.p.m. of NH_4- and NO_3-N, respectively. After one week's growth in solution cultures, in which the seed was removed from the seedling, there is a decrease in NH_4-N content and an accumulation of NO_3-N. This indicates a rapid utilization of NH_4 in the growth processes with little if any utilization of NO_3 nitrogen. It would be interesting to study the relation of growth to the form of available nitrogen furnished alone by the seed.

An interesting phase of this investigation was that seedlings absorbed more NH_4- than NO_3-N in their early stages, then the reverse was true and more NO_3- than NH_4-N was absorbed. A theoretical discussion of these phenomena follows. In new or young tissue there is an abundance of asparagine, and it is quite reasonable to believe that NH_4-N will supply the source of N for asparagine more rapidly than NO_3-N (7). This may be taken as evidence of the more rapid utilization of the NH_4 form of N. Another view of the phenomenon of absorption is that the cell colloids absorb ions until they are saturated with respect to this ion (4). No further absorption of the ion occurs until it is removed when active absorption is again resumed. The NH_4 and NO_3 ions should be removed very rapidly as compared with other ions, and the NH_4 more rapidly in young plants than the NO_3 ion. It is then possible for the cell to absorb more NH_4 than NO_3 ions as long as there is a high utilization of asparagine. The relative amounts of NH_4 utilized by the plant becomes less as it grows older and the percentage of new tissue decreases. This is in accord with the results of this investigation.

Any explanation of the absorption phenomena should consider that the NH_4 ion is a cation and the NO_3 ion an anion; that is, they have opposite charges. It must be in accord with the established physico-chemical laws of colloidal chemistry. It is known that the charge of the cell colloid partially determines the absorption of cations or anions, and that this is influenced by the pH of the exterior medium. Should the pH be above the isoelectric point of the cell colloid more cations will be absorbed, and if the pH is below the isoelectric point the cell colloids will have a positive charge and more anions will be absorbed. At the isoelectric point there will be no absorption of either ion or equal absorption of both. It may be that unequal absorption of ions is influenced by the charge of the colloids.

Data obtained from studies of the NH_4- and NO_3-N content and pH of the sap obtained from plants at different ages show an interesting relationship. There appears to be a certain stage of growth and pH at which there is an equal absorption and apparently equal utilization of the two ions. It is possible that the reaction at this stage is at the isoelectric point of the cell colloids.

There is no explanation to be offered why there is a higher utilization of the NO_3- than NH_4-N in the later stages of growth. It is known that the NH_4 ion in high concentrations is toxic to plants and that its toxicity is influenced by the reaction and the presence of other factors. It is possible that there is a change in the degree of dispersity of the colloidal structure of the protoplasma which influences

the absorption and utilization of the NH_4- and NO_3-N. These explanations, however, are theoretical and highly complex even though they are in accord with absorption principles. They at least open up an avenue of thought for future study.

SUMMARY

Experiments are reported in which a study was made of the absorption of NH_4- and NO_3-N and plant growth by cotton seedlings. The seedlings were grown in solution, sand, and soil cultures. The solution cultures were used in a series designed to study the influence of various concentrations of NH_4- and NO_3-N on the absorption of these ions. The effect of the age of the seedlings, reaction of the culture solution, and length of the absorption period on the relative amounts of NH_4- and NO_3-N removed from the culture solutions were studied. Results of a study of the NH_4- and NO_3-N content and the pH value of sap from plants at different ages are included. The results of the investigation may be briefly summarized as follows:

1. NH_4-N was used in larger amounts than NO_3-N by the young seedlings until they were from 3 to 5 weeks old. After this age more NO_3-N was absorbed.
2. The data show that both NH_4- and NO_3-N were absorbed in large amounts when the plants were 4 to 8 weeks old.
3. Both growth and fruiting of plants were largest when both forms of nitrogen were present.
4. NH_4-N absorption increased as the acidity of the culture solution decreased; the absorption of NO_3-N was only slightly affected by the reaction of the solution used.
5. The highest total nitrogen absorption usually occurred at pH 6.0.
6. Total nitrogen absorption was greatest when both forms of nitrogen were present.
7. The growth and fruiting of cotton in field plats agreed well with that of the culture solutions.
8. Data are presented which indicate that nitrogen in the seed is available to the sprouts and young seedlings in the NH_4 form.
9. A theoretical discussion of the observed absorption phenomenon is included.

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NOTE

THE AGRONOMIST AND THE SEED LABORATORY

There is every evidence of lack of cooperation between agronomists, particularly extension agronomists, and the several seed testing laboratories. There are a few important reasons for this condition that are worthy of serious study. In some instances, the seed laboratory, often being a purely political venture, deals exclusively with seed control or enforcement of the seed law and ignores the great public service projects just at hand. In other instances, the seed laboratory apparently has not sought out, or else rejects the opportunities to reach the public through the extension agronomist and attempts to carry on its own program, and *vice versa*. In this connection the writer would like to interest the extension agronomist and the seed laboratory in a common program.

There is no other one commodity that the farmer uses like seed stocks with their many varieties, grades, and uses. Since seed stocks are very variable and seasonable, it would seem absolutely essential that any information or extension material gained by the seed laboratory should be extended immediately to the grower of crops. It is not enough simply to compile data in an official report after the planting season is past. Great quantities of seed stocks pass through the seed laboratories yearly, and in many instances the knowledge gained from this source is largely lost, so far as the planter is concerned.

Extension facilities are set up in each State and should be made use of constantly by the seed analyst. The seed laboratory can deal effectively with origin, variety, purity, vitality, and disease of field crop, vegetable, lawn, flower, and tree seeds, and should have full access to and cooperate with the extension forces in the respective departments concerned with these kinds of seeds. Likewise, it behooves the extension worker in those departments concerned to cooperate with and use the timely findings of the seed laboratory.

Perhaps in most states the best contact with the farmer is through the extension agronomist. There are many ways by which the agron-

omist can support the seed testing work and put it on an effective working basis. There is no state too small to support a small though effective and efficient seed laboratory. This year, when seed stocks will play so large a part in profitable crop production, is a good time to begin effective cooperation.—M. T. MUNN, *Chief in Research in Charge of Seed Laboratory, State Experiment Station, Geneva, N. Y.*

AGRONOMIC AFFAIRS

SUMMER MEETING OF CORN BELT SECTION

The summer meeting of the Corn Belt Section of the Society is to be held at Purdue University on June 22 and 23, according to present plans, with details of the program to be announced later.

THE LENIN ACADEMY OF AGRICULTURAL SCIENCE

The Editor is indebted to J. W. Pincus for the following statement regarding the organization of the Lenin Academy of Agricultural Science.

The recent decree issued by the Commissariat of Agriculture at U. S. S. R. has affected a complete reorganization of the various Institutes composing the Lenin Academy of Agricultural Science. In addition to 16 main Institutes or Bureaus in the Academy, there are a large number of Special Institutes, which, in turn, have Regional Institutes and Experiment Stations. One of the most important and the oldest Institute is that of Plant Industry, formerly known as the Institute of Applied Botany and New Cultures. Acadamician N. I. Vavilov, who with his associate, Professor N. Kuleshow, recently visited the United States, is at the head of this Institute as well as of the whole Academy. This Institute has a large number of special branches located in Ukrain, Crimea, Caucasus, Asia, etc.

The Institute of Agricultural Soil Science, with Dr. V. P. Bushinsky at the head and with headquarters in Moscow; and the Institute of Agricultural Micro-Biology, with Acadamician S. P. Kostychev as Director, are also of interest to American agronomists. Two important Bureaus in connection with the Institutes are the principal Library and the Bureau for post graduate students. Among the special Institutes might be mentioned those on Grain, Soybeans, Corn, Potatoes, etc. There is also a special Institute on Drought Control located at Saratov under the Directorship of Professor N. Tulaikov, one of the vice-presidents of the Academy and well known to many American agronomists.

SOUTHWESTERN AGRONOMISTS MEETS

A winter meeting of the Southwestern agronomists, representing the states of Arkansas, Louisiana, Oklahoma, and Texas, was held at Atlanta, Georgia, February 3, in conjunction with the annual meeting of the Southern Agricultural Workers' Association.

Agronomists from the states represented discussed at length the results of field work in their respective states. These reports were followed by a general discussion of some of the leading problems of common interest to agronomists of the Southwest.

NEWS ITEMS

DR. M. M. McCOOL, formerly head of the Department of Soils, Michigan State College, has accepted a position with the Boyce Thompson Institute at Yonkers, N. Y.

AT A recent meeting of the Iowa Section of the American Society of Agronomy; the following officers were elected for the ensuing year: *President*, H. R. Meldrum, *Vice-President*, R. H. Walker; *Secretary-Treasurer*, John B. Peterson.

DR. WILLIAM A. ALBRECHT of the Department of Soils, University of Missouri, who returned recently from the International Soil Congress and travels in Europe, will spend the coming semester at Cornell University.

H. L. WESTOVER of the Office of Forage Crops and Diseases, United States Department of Agriculture, spoke before the Iowa Section of the American Society of Agronomy on January 14, telling of some of his observations and experiences in Africa and Turkestan.

STANLEY F. MORSE, consulting agriculturist of South Carolina and New York City, who is making a business trip and studying agricultural and economic conditions in England, France, Spain, and Italy, has just completed an inspection and report of a 150,000-acre irrigation project in southern Spain.

JOURNAL

OF THE

American Society of Agronomy

Vol. 23 March, 1931 No. 3

CROP PLANTS UNDER CULTIVATION IN JAPAN[1]

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How many crop plants are cultivated throughout the world? This is an interesting question both from the botanical and the agronomic standpoint. So far, some authors, such as Blomeyer and Sturtevant, have attacked this problem, but with little success. The writer has been engaged in a similar study since 1928. First of all, though, it seemed desirable to list the kinds of crop plants in Japan, not to say of the world. Thus far, no attempt had been made in this direction, at least no reports thereon have been issued. The studies reported here were begun in the summer of 1928 and were briefly reported upon in 1929 and again in 1930 in *Agriculture and Horticulture* (Japanese). The present paper summarizes the result of investigation thus far obtained, with some brief modifications.

As a preliminary step in this study a list of Japanese crop plants was prepared based essentially on the writer's experience, but with more or less reference to publications on plant production and with the kind help of friends and colleagues. The list thus prepared was sent to the prefectural agricultural experiment stations throughout Japan asking for information on crop plants under cultivation in their respective region. For particular plants, inquiry was also made to the livestock experiment stations, the hygienic laboratories, etc. Replies were received from all except a few, and the information thus secured has afforded very useful material for the investigation. Some crop plants not thus far noted in agricultural literature have been identified. The answers were compared carefully with the original list, and after much trouble, Japanese, English, scientific, and family names have been identified for all the plants.

[1]Contribution from the Division of Plant Breeding, College of Agriculture, Hokkaido Imperial University, Sapporo, Japan. Received for publication November 8, 1930.

[2]Professor of Plant Breeding.

In executing this study it was thought necessary to determine the meaning of the term "crop plants." This would seem to be a very simple matter at first sight, but in reality this was not the case. Crop plants in this paper include all of those plants cultivated for economic purposes, thus excluding plants grown only as specimens or for trial. Moreover, plants grown only to satisfy the artistic taste were not included, even though they may be grown on a large scale and with an economic purpose. The extent of cultivation is not important in the main, but it must be appreciated that, so far as crop plants are concerned, they must be cultivated more or less in bulk. For instance, assuming that a farmer grows two or three plants of wild grape in his garden with an economic purpose, undoubtedly it is not appropriate in this case to call the wild grape a crop plant. It is necessary in order to include it as a crop plant that such farmers exist in large numbers or that a single farmer cultivates wild grapes extensively. In the list presented here, for example, *Akebia quinata*, *Myrica rubra*, etc., were listed as food plants in the former sense and *Vaccinium Vitis-Idaea* in the latter sense. However, it is sometimes difficult to determine the extent of cultivation of a crop plant, so that to some extent the classification must be rather arbitrary.

Furthermore, granting that a crop plant is really concerned, there still remains on occasion some difficulties to determine whether it is better to regard it either as an independent crop plant or as a mere subdivision. This is especially so with pickling cabbage belonging to the genus Brassica, as well as with the citrus fruits. Quite a number of distinct species of pickling cabbage are under cultivation so that either pickling cabbage as a whole or any one of its several subdivisions may be considered as a crop plant. In the latter case, there still remains the question as to which subdivisions deserve mention as independent crop plants. Exactly the same thing may be said of citrus fruits. An accurate answer may be given only on the basis of a precise investigation of both the agronomic and botanical characters. In the present study, more weight has been given to the agronomic characters than to botanical characters in accordance with the nature of the plants under consideration. Here again, however, classification is rather arbitrary.

Much attention has been paid to the classification of crop plants. The term industrial plant, much used in agricultural literature, has been abandoned as it seems inadequate for use in a systematic classification of crop plants. For instance, starch and sugar crops are generally looked upon as industrial plants; but so far as the division of food crops is concerned, it seems better to enumerate all plants grown

for food, even when used for industrial purposes, as food crops. In this paper, crop plants have been divided into 19 categories according to their uses, occasionally with certain subdivisions, though this will not be sufficient for a classification of the world's crop plants.

As a matter of fact, there are a number of crop plants adapted to various uses, so that some plants may be included in several divisions. In this case, for the sake of brevity, only the more important uses have been taken into consideration. However, for certain plants, less important use has been taken into account when it is peculiar in nature and of general interest. For instance, *Brassica juncea* has been put into the division of flower crops, notwithstanding the fact that it is grown essentially for its foliage.

In crop plants there are some which involve species hybrids, as are frequently met with in bud-propagated plants. However, since the aim of this study is to learn the kinds of crop plants, together with their respective species and varieties, species hybrids have not been mentioned in the list.

The Japanese names used in the present list have been taken mainly from *The Flora of Japan*, by T. Makino and K. Nemoto, published in 1924. The scientific names have been derived mostly from Bailey's *Manual of Cultivated Plants*, unless not cited there, when Makino and Nemoto's work has been consulted. With respect to mushrooms, Kawamura's *Japanese Mushrooms*, published in 1929, has also been consulted. Most of the English names are from Bailey's *Manual*, but at times Van Wijk's *Dictionary of Plantnames*, published in 1911, and Macmillan's *Handbook of Tropical Gardening and Planting*, Ed. 3, published in 1925, have been referred to.

With the above-mentioned limitations in mind, the list of Japanese crop plants follows in Table 1. It should be stated that the crop plants have been listed in the table in the alphabetical order of their respective family names, but that these names do not appear in the table for sake of economy of space.

TABLE 1.—*A list of crop plants under cultivation in Japan.*

Common Japanese name	Common English name (if any)	Scientific name
	I. Food Crops	
	1. Grain Crops	
	a. Cereal Crops	
Ine	Rice	*Oryza sativa* L.
Omugi	Barley	*Hordeum vulgare* L.
Komugi	Wheat	*Triticum aestivum* L.
Embaku	Oats	*Avena sativa* L.
Raimugi	Rye	*Secale cereale* L.
Awa	Foxtail millet	*Setaria italica* Beauv.

TABLE 1.—*Continued*

Common Japanese name	Common English name (if any)	Scientific name
	a. Cereal Crops—*Cont.*	
Kibi	Millet	*Panicum mileaceum* L.
Morokoshi	Grain sorghum	*Holcus Sorghum* L. var. *caffronum* Bailey
To-morokoshi	Maize	*Zea Mays* L.
Hie	Japanese barnyard millet	*Echinochloa frumentacea* Link.
Shikoku-bie	African millet	*Eleusine coracana* Gaertn.
Hatomugi	Job's tears	*Coix Lacryma*-Jobi L.
	b. Legume Crops	
Daizu	Soybean	*Glycine Max* Merr.
Azuki	Adzuki bean	*Phaseolus angularis* Wight
Yaenari	Mung bean	*Phaseolus aureus* Roxb.
Ingen-mame	Kidney bean	*Phaseolus vulgaris* L.
Hana-mame	Multiflora bean	*Phaseolus coccineus* L.
Raima-mame	Lima bean	*Phaseolus limensis* Macf.
Endo	Pea	*Pisum sativum* L.
Sora-mame	Broad bean	*Vicia Faba* L.
Sasage	Cowpea	*Vigna sinensis* Endl.
Hata-sasage	Catjang	*Vigna Catjang* Walp.
Nata-mame	Sword bean	*Canavalia gladiata* DC.
Fuji-mame	Hyacinth bean	*Dolichos Lablab* L.
Nankin-mame	Peanut	*Arachis hypogaea* L.
Ki-mame	Pigeon bean	*Cajanus Cajan* Millsp.
	c. Miscellaneous Grain Crops	
Senninkoku	Love lies bleeding	*Amaranthus caudatus* L.
Sotetsu*	Sago palm	*Cycas revoluta* Thunb.
Chosen-matsu	———	*Pinus koraiensis* Sieb. et Zucc.
Soba	Buckwheat	*Fagopyrum esculentum* Gaertn.
	2. Root Crops	
Tsurigane-ninjin	———	*Adenophora latifolia* Fisch.
Sangojuna	Garden beet	*Beta vulgaris* L.
Gobo	Great burdock	*Arctium Lappa* L.
Baramonjin	Salsify	*Tragopogon porrifolius* L.
Satsuma-imo	Sweet potato	*Ipomoea Batatas* Lam.
Daikon	Oriental radish	*Raphanus sativus* L. var. *longipinnatus* Bailey
Hatsuka-daikon	Radish	*Raphanus sativus* L.
Kabura	Turnip	*Brassica Rapa* L.
Naga-imo	Chinese Yam	*Dioscorea Batatas* Decne.
Imonoki	Cassava	*Manihot utilissima* Pohl.
Kuzu-imo	Yam bean	*Pachyrhizus erosus* Urb.
Tenmondo†	———	*Asparagus lucidus* Lindl.
Yama-gobo	———	*Phytolacca esculenta* Van Houtte
Ninjin	Carrot	*Daucus Carota* L. var. *sativa* DC.
Amerika-bofu	Parsnip	*Pastinaca sativa* L.
Konyo-oranda-mitsuba	Celeriac	*Apium graveolens* L. var. *rapaceum* DC.

*Starch is obtained from seeds and stems.
†A kind of confection is prepared.

TABLE 1.—*Continued*

	3. Subterranean Stem Crops	
Kuwai	————	*Sagittaria trifolia* L. var. *sinensis* Makino f. *caerulea* Makino
Sato-imo	Taro	*Colocasia esculenta* Schott
Konniaku	————	*Amorphophallus Konjak* C. Koch
Kiku-imo	Jerusalem artichoke	*Helianthus tuberosus* L.
O-kuroguwai	————	*Eleocharis plantaginea* R. Br.
Chorogi	Japanese artichoke	*Stachys Sieboldi* Miq.
Tama-negi	Onion	*Allium Cepa* L.
Rakkio	————	*Allium Bakeri* Regel
Ninniku	Garlic	*Allium sativum* L.
Oni-yuri	Tiger lily	*Lilium tigrinum* Ker.
Ko-oni-yuri	————	*Lilium Maximowiczii* Regel
Hime-yuri	————	*Lilium concolor* Salisb.
Kuzu-ukon	Arrowroot	*Maranta arundinacea* L.
Hasu	East Indian lotus	*Nelumbo nucifera* Gaertn.
Jaga-imo	Potato	*Solanum tuberosum* L.
	4. Aerial Stem Crops	
Udo	————	*Aralia cordata* Thunb.
Kiukei-tamana	Kohlrabi	*Brassica caulorapa* Pasq.
Sotetsu	Sago palm	*Cycas revoluta* Thunb.
Sugina‡	Common horsetail	*Equisetum arvense* L.
Moso-dake	————	*Phyllostachys mitis* Riv.
Hachiku	————	*Phyllostachys puberula* var. *Henonis* Makino
Ma-dake	————	*Phyllostachys reticulata* C. Koch
Makomo§	Canada rice	*Zizania aquatica* L.
Matsuba-udo	Asparagus	*Asparagus officinalis* L. var. *altilis* L.
Uwabamiso	————	*Elatostema umbellatum* Blume var. *convolucratum* Makino
	5. Leaf Crops	
Tsuruna	New Zealand spinach	*Tetragonia expansa* Murr.
Hageito	Joseph's coat	*Amaranthus tricolor* L.
Hiyu	————	*Amaranthus mangostanus* L.
Hasu-imo	Taro	*Colocasia gigantea* Hook. f.
Ukogi	————	*Acanthopanax pentaphyllum* March
Horenso	Spinach	*Spinacea oleracea* L.
Fudanso	Swiss chard	*Beta vulgaris* L. var. *Cicla* L.
Matsuna	————	*Suaeda glauca* Bunge
Oka-hijiki	————	*Salsola Soda* L.
Chisa	Lettuce	*Lactuca sativa* L.
Shungiku	Garland chrysanthemum	*Chrysanthemum coronarium* L.
Fuki	Butterbur	*Petasites japonicus* Miq.
Niga-chisa	Endive	*Cichorium Endivia* L.
Tampopo	Dandelion	*Taraxacum officinale* Weber
Suizenjina	————	*Gynura bicolor* DC.
Yomogina	Mugwort	*Artemisia lactiflora* Wall
Yosai	Swamp cabbage	*Ipomoea aquatica* Forsk.
Tamana	Cabbage	*Brassica oleracea* L. var. *capitata* L.
Komochi-tamana	Brussels sprouts	*Brassica oleracea* L. var. *gemmifera* Zenker.
Hagoromo-tamana	Kale	*Brassica oleracea* L. var. *acephala* DC.

‡Young flower stalk is edible.
§Stem infested by a peculiar fungus is edible.

TABLE 1.—*Continued*

Common Japanese name	Common English name (if any)	Scientific name
	5. Leaf Crops—*Cont.*	
Hakusai	Chinese cabbage	*Brassica pekinensis* Rupr.
Taisai	White-mustard cabbage	*Brassica chinensis* L.
Takana	Chinese mustard	*Brassica juncea* Coss.
Karashina	Mustard	*Brassica alba* Rabenh.
		Brassica nigra Koch
Mizuna	————	*Brassica japonica* Sieb.
Suigukina	————	*Brassica japonica*Sieb. var. *suigukina* Makino
Komatsuna	————	*Brassica Napus* L. var. *komatsuna* (Matsum. et Nakai)
Togoma	Castor bean	*Ricinus communis* L.
Negi	Welsh onion	*Allium fistulosum* L.
Nira	————	*Allium odorum* L.
Wakegi	Shallot	*Allium oscalonicum* L.
Asatsuki	————	*Allium Ledebourianum* Schult. f.
Ezo-negi	Chive	*Allium schoenoprasm* L.
Nira-negi	Leek	*Allium Porrum* L.
Okanori	Curled mallow	*Malva crispa* L.
Chosen-huyu-awoi	————	*Malva olitoria* Nakai
Daio	Garden rhubarb	*Rheum Rhaponticum* L.
Suiba	Garden sorrel	*Rumex Acetosa* L.
Warabi	Wild brake	*Pteridium aquilinum* Kuhn.
Seri	Water dropwort	*Oenanthe stolonifera* DC.
Mitsuba	Honewort	*Cryptotaenia canadensis* DC. var. *japonica* Makino
Hama-bofu	————	*Rhellopterus littoralis* Benth.
Oranda-mitsuba	Celery	*Apium graveolens* L. var. *dulce* DC.
Botan-ninjin	————	*Peucedanum japonicum* Thunb.
Koendoro	Coriander	*Coriandrum sativum* L. -
Ashitaba	————	*Angelica utilis* Makino
No-chisa	Corn salad	*Valerianella Locusta* Betcke var. *olitoria* L.
	6. Flower Crops	
Riori-giku	Florist's chrysanthemum	*Chrysanthemum morifolium* Ram.
Chosen-azami	Artichoke	*Cynara Scolymus* L.
Fuki	Butterbur	*Petasites japonicus* Miq.
Hanayasai	Cauliflower	*Brassica oleracea* L. var. *botrytis* L.
Kidachi-hanayasai	Broccoli	*Brassica oleracea* L. var. *botrytis* L.
Takana	Chinese mustard	*Brassica juncea* L.
Ninniku	Garlic	*Allium sativum* L.
Yabu-kanzo	Orange day lily	*Hemeracallis fulva* L. var. *Kwanso* Regel
	7. Fruit Crops	
	a. Vegetable Fruits	
Hori	Pineapple	*Ananas comosus* Merr.
Araseito	Stock	*Mathiola incana* R. Br.
Kiuri	Cucumber	*Cucumis sativus* L.
Makuwa-uri	Muskmelon	*Cucumis Melo* L.
Suikwa	Watermelon	*Citrullus vulgaris* Schrad.
Hechima	Rag gourd	*Luffa cylindrica* Roem.
Tsuru-reishi	Balsam pear	*Momordica Charantia* L.
Togan	White gourd	*Benincasa hispida* Cogn.

TABLE 1.—*Continued*

Yugawo	Calabash gourd	*Lagenaria vulgaris* Ser. var. *clavata* Ser.
Kabocha	Pumpkin and squash	*Cucurbita Pepo* L.
		Cucurbita moschata Duchesne
		Cucurbita maxima Duchesne
Shiro-uri	Oriental pickling melon	*Cucumis Melo* L. var. *Conomon* Makino
Hayato-uri	Chayote	*Sechium edule* Sw.
Sasage	Cowpea	*Vigna sinensis* Endl.
	Asparagus bean	*Vigna sesquipedalis* W. F. Wight
Nankin-mame	Peanut	*Arachis hypogaea* L.
Ingen-mame	Kidney bean	*Phaseolus vulgaris* L.
Daizu	Soybean	*Glycine Max* Merr.
Endo	Pea	*Pisum sativum* L.
Amerika-neri	Okra	*Hibiscus esculentus* L.
Mi-basho	Banana	*Musa paradisiaca* L. var. *sapientum* Kuntze
Hishi	Water chestnut	*Trapa natans* L.
Kudamono-tokei	Purple granadilla	*Passiflora edulis* Sims.
O-nagami-kudamono-tokei	Giant granadilla	*Passiflora quadrangularis* L.
Oranda-ichigo	Strawberry	*Fragaria chiloensis* Duchesne var. *ananassa* Bailey
Nasu	Eggplant	*Solanum Melongena* L.
Aka-nasu	Tomato	*Lycopersicum esculentum* Mill.

b. Non-Vegetable Fruits

Mango	Mango	*Mangifera indica* L.
Ban-reishi	Sweetsop	*Annona squamosa* L.
Toge-ban-reishi	Soursop	*Annona muricata* L.
Giushinri	Common custard apple	*Annona reticulata* L.
————	Karanda	*Carissa Carandas* L.
Kanran	————	*Canarium album* Raeusch
Papaya	Papaya	*Carica Papaya* L.
Kaki	Persimmon	*Diospyros Kaki* L. f.
Ke-gaki	Velvet apple	*Diospyros discolor* Willd.
Gumi	————	*Elaeagnus pungens* Thunb.
		Elaeagnus multiflora Thunb.
		Elaeagnus umbellata Thunb.
————	Ceylon olive	*Elaeocarpus serratus* L.
Yukan	Emblic	*Phyllanthus Emblica* L.
Kuri	Japanese chestnut	*Castanea crenata* Sieb. et Zucc.
Icho	Ginkgo	*Ginkgo biloba* L.
Kurumi	Walnut	*Juglans Sieboldiana* Maxim.
		Juglans Sieboldiana Maxim. var. *cordiformis* Makino
		Juglans regia L. var. *sinensis* C. DC.
Akebi	————	*Akebia quinata* Decne.
Mube	————	*Stauntonia hexaphylla* Decne.
————	Roselle	*Hibiscus Sabdariffa* L.
Ichijiku	Fig	*Ficus carica* L.
Pannoki	Breadfruit	*Artocarpus communis* Forst
Haramitsu	Jakfruit	*Artocarpus integra* Merr.
Aigiokushi-itabi	————	*Ficus Awkeotsang* Makino
Yama-momo	————	*Myrica rubra* Sieb. et Zucc.
————	Avocado	*Persea americana* Mill.
O-futomomo	Wax jambo	*Eugenia javanica* Lam.
Futomomo	Rose apple	*Eugenia Jambos* L.
Banjiro	Guava	*Psidium Guajava* L.
————	Strawberry guava	*Psidium Cattleianum* Sabine.
Gorenshi	Carambola	*Averrhoa Carambola* L.

TABLE I.—*Continued*

Common Japanese name	Common English name (if any)	Scientific name
	b. Non-Vegetable Fruits—*Cont.*	
Zakuro	Pomegranate	*Punica Granatum* L.
Natsume	Common jujube	*Zizyphus Jujuba* Mill.
Ringo	Apple	*Pyrus Malus* L.
Nashi	Sand pear	*Pyrus serotina* Rehd, var. *culta* Rehd.
Seiyo-nashi	Pear	*Pyrus communis* L.
Marumero	Quince	*Cydonia oblonga* Mill.
Biwa	Loquat	*Eriobotrya japonica* Lindl.
Momo	Peach	*Prunus Persica* Sieb. et Zucc.
Zubai-momo	Nectarine	*Prunus Persica* Sieb. et Zucc. var. *nucipersica* Schneid.
Anzu	Apricot	*Prunus Armeniaca* L.
Yusura-ume	————	*Prunus tomentosa* Thunb.
Niwa-ume	————	*Prunus japonica* Thunb.
Ume	Japanese apricot	*Prunus Mume* Sieb. et Zucc.
Mizakura	Cherry	*Prunus avium* L. *Prunus Cerasus* L. *Prunus pseudo-Cerasus* Lindl.
Sumomo	Plum	*Prunus salicina* Lindl. *Prunus domestica* L.
Kwarin	Chinese quince	*Chaenomeles sinensis* Koehne
Mikan	King orange	*Citrus nobilis* Lour.
Tento	Sweet orange	*Citrus sinensis* Osbeck
Zabon	Grapefruit	*Citrus maxima* Merr.
Natsu-daidai	————	*Citrus Aurantium* L. Subsp. *Natsudaidai* Hayata
Kinkan	Kumquat	*Fortunella margarita* Swingle
Wampi	Wampi	*Claucena Lancium* Skeels
Riugan	Longan	*Euphoria Longana* Lam.
Ban-riugan	————	*Pometia pinnata* Forst.
Reishi	Litchi	*Litchi chinensis* Sonn.
————	Sapote	*Achras Zapota* L.
Suguri	Gooseberry	*Ribes hirtellum* Michx. *Ribes Grossularia* L.
Fusa-suguri	Currant	*Ribes sativum* Syme
Pimpon	————	*Sterculia nobilis* R. Br.
Kaya	————	*Torreya nucifera* Sieb. et Zucc.
Budo	Grape	*Vitis vinifera* L. *Vitis Labrusca* L.
	8. Mushroom Crops	
Hara-take	Common mushroom	*Agaricus campestris* L.
Matsu-dake	————	*Armillaria Matsudake* Ito et Imai
Enoki-dake	————	*Collybia velutipes* (Curt.) Fr.
Shii-take	————	*Cortinellus Shiitake* P. Henn.
	II. Relish Crops	
	1. Aromatic Crops	
Shiso	Perilla	*Perilla frutescens* Britt.
Tachi-jakoso	Common thyme	*Thymus vulgaris* L.
Sarubia	Sage	*Salvia officinalis* L.
Hakka	Japanese mint	*Mentha arvensis* L. var. *piperascens* Malinvaud.
Ninniku	Garlic	*Allium sativum* L.
Juran	————	*Aglaea odorata* Lour.
Hoppu	Hop	*Humulus lupulus* L.
Morinkwa	Arabine Jasmine	*Jasminium Sambac* Ait.
Kisokei	Jonquil-scented jasmine	*Jasminium odoratissimum* L.

TABLE 1.—*Continued*

Keshi	Opium poppy	*Papaver somniferum* L.
Goma	Sesame	*Sesamum orientale* L.
Kuchinashi	Cape jasmine	*Gardenia jasminoides* Ellis
Remon	Lemon	*Citrus Limonia* Osbeck
Yuzu	————	*Citrus Aurantium* L. subsp. *Junos* Makino
Busshukan	Citron	*Citrus medica* L.
Oranda-zeri	Parsley	*Petroselinum hortense* Hoffm.
Mioga**	————	*Zingiber Mioga* Rosc.
	2. Pungent Crops	
Wasabi	————	*Eutrema Wasabi* Maxim.
Koshoso	Garden cress	*Lepidium sativum* L.
Karashina	Mustard	*Brassica alba* Rabenh. *Brassica nigra* Koch
Wasabi-daikon	Horseradish	*Armoracia rusticana* Gaertn.
Tade	Water pepper	*Polygonum Hydropiper* L.
Sansho	————	*Xanthoxylum piperitum* DC.
Togarashi	Red pepper	*Capsicum frutescens* L.
Nozenharen	Garden nasturtium	*Tropaeolum majus* L.
Shoga	Ginger	*Zingiber officinale* Rosc.
	3. Sour Crops	
Daidai	Sour orange	*Citrus Aurantium* L. subsp. *amara* Engl.
Ume	Japanese apricot	*Prunus Mume* Sieb. et Zucc.
	4. Sugar Crops	
Sato-daikon	Sugar beet	*Beta vulgaris* L.
Sato-kibi	Sugarcane	*Saccharum officinarum* L.
	III. Forage Crops	
	1. Gramineous Crops	
Embaku	Oats	*Avena sativa* L.
Omugi	Barley	*Hordeum vulgare* L.
To-morokoshi	Maize	*Zea Mays* L.
O-awagaeri	Timothy	*Phleum pratense* L.
Kamo-gaya	Orchard grass	*Dactylis glomerata* L.
Konuka-gusa	Redtop	*Agrostis palustris* Huds.
Nagaha-gusa	Kentucky bluegrass	*Poa pratensis* L.
Tachi-ichigo-tsunagi	Wood meadow grass	*Poa nemoralis* L.
————	Guinea grass	*Panicum maximum* Jacq.
Hirohano-ushinoke-gusa	Meadow fescue	*Festuca elatior* L.
O-ushinoke-gusa	Red fescue	*Festuca rubra* L.
Haru-gaya	Sweet vernal grass	*Anthoxanthum odoratum* L.
O-kanitsuri	Tall oat-grass	*Arrhenatherum elatius* Mert. et Koch
Kanitsuri-gusa	Yellow oat grass	*Trisetum flavescens* Beauv.
O-suzumeno-teppo	Meadow foxtail	*Alopeculus pratensis* L.
Kushi-gaya	Crested dogs tail	*Cynosurus cristatus* L.
Hoso-mugi	Perennial ryegrass	*Lolium perenne* L.
Nezumi-mugi	Italian ryegrass	*Lolium multiflorum* Lam.
Tojin-kibi	Pearl millet	*Pennisetum glaucum* R. Br.
Hachijo-susuki	Eularia	*Miscanthus sinensis* Anders. var. *condensatus* Makino
	2. Leguminous Crops	
Aka-tsumekusa	Red clover	*Trifolium pratense* L.
Shiro-tsumekusa	White clover	*Trifolium repens* L.
————	Alsike clover	*Trifolium hybridum* L.
————	Mammoth clover	*Trifolium pratense* L. var. *perenne* Host

**Young flower buds and stems are used.

TABLE 1.—*Continued*

Common Japanese name	Common English name (if any)	Scientific name
	2. Leguminous Crops—*Cont.*	
Murasaki-umago-yashi	Alfalfa	*Medicago sativa* L.
Genge	Milk vetch	*Astragalus sinensis* L.
Yahazu-endo	Common vetch	*Vicia sativa* L.
Ke-yahazu-endo	Hairy vetch	*Vicia villosa* Roth.
Shiro-hagi	———	*Lespedeza japonica* Bailey
Daizu	Soybean	*Glycine Max* Merr.
	3. Miscellaneous Forage Crops	
Tensai	Mangels	*Beta vulgaris* L.
Kiku-imo	Jerusalem artichoke	*Helianthus tuberosus* L.
Satsuma-imo	Sweet potato	*Ipomoea Batatas* Lam.
Suweden-kabu	Rutabaga	*Brassica Napobrassica* Mill.
Kabura	Turnip	*Brassica Rapa* L.
Aburana	Rape	*Brassica Napus* L.
Kabocha	Pumpkin and squash	*Cucurbita* spp.
Kuwa	Mulberry	*Morus bombysis* Koidz. *Morus alba* L. *Morus multicaulis* Perr.
Jaga-imo	Potato	*Solanum tuberosum* L.
Ninjin	Carrot	*Daucus Carota* L. var *sativa* DC.
	IV. Medical Crops	
Omodaka	Old World arrow-head	*Sagittaria sagittifolia* L.
Inoko-zuchi	———	*Achyranthes bidentata* Blume
Otane-ninjin	Asiatic ginseng	*Panax Ginseng* C. A. Mey.
Nanten	Sacred bamboo	*Nandina domestica* Thunb.
Tsurigane-ninjin	———	*Adenophora latifolia* Fisch.
Kikio	Balloon flower	*Platycodon grandiflorum* A. DC.
Aritaso	———	*Chenopodium ambrosioides* L.
Jochu-giku	Insect powder plant	*Chrysanthemum cinerariaefolium* Vis.
Oguruma	Elecampane	*Inula Helenium* L.
Kamitsure	Wild chamomile	*Matricaria Chamomilla* L.
Asagawo	Morning glory	*Ipomoea Nil* Roth
Yamano-imo	———	*Dioscorea japonica* Thunb.
Togoma	Castor bean	*Ricinus communis* L.
Hazu	Croton	*Croton Tiglium* L.
Hatomugi	Job's tears	*Coix Lachryma* Jobi L.
Safuran	Saffron	*Crocus sativus* L.
Hakka	Japanese mint	*Mentha arvensis* L. var. *piperascens* Malinvaud.
Sarubia	Sage	*Salvia officinalis* L.
Nikkei	Cinnamon	*Cinnamomum Loureirii* Nees
Habuso	Hedionda	*Cassia occidentalis* L.
Ebisu-gusa	Wild senna	*Cassia Tora* L.
Kanzo	Licorice	*Glycyrrhiza glabra* L.
Baimo	———	*Fritillaria verticillata* Willd. var. *Thunbergii* Bak.
Hana-suge	———	*Anemarrhena asphodeloides* Bunge.
Ninniku	Garlic	*Allium sativum* L.
Yaburan	———	*Liriope graminifolia* Bak.
Jano-hige	———	*Ophiopogon japonicus* Ker.
Usubeni-tachi-awoi	Marsh mallow	*Althaea officinalis* L.
Keshi	Opium poppy	*Papaver somniferum* L.
Yama-gobo	———	*Phytolacca esculenta* Van Houtte

TABLE I.—*Continued*

Kara-daio	Rhubarb	*Rheum undalatum* L.
Zakuro	Pomegranate	*Punica Granatum* L.
Oren	————	*Coptis japonica* Makino
Shakuyaku	Peony	*Paeonia albiflora* Pall.
Botan	Tree peony	*Paeonia Moutan* Sims.
Anzu	Apricot	*Prunus Armeniaca* L.
Bakuchino-ki	————	*Prunus macrophylla* Sieb. et Zucc.
Kuchinashi	Cape jasmine	*Gardenia jasminoides* Ellis
Henruda	Common rue	*Ruta graveolens* L.
Goshuyu	————	*Evodia rutaecarpa* Hook. f. et Thoms.
Sansho	————	*Xanthoxylum piperitum* DC.
Daidai	Sour orange	*Citrus aurantium* L. subs. *amara* Engl.
Amacha	————	*Hydrangea opuloides* Steud. var. *Thunbergii* Makino
Kitsuneno-tebukuro	Common foxglove	*Digitalis purpurea* L.
Jiwo	————	*Rehmannia glutinosa* Libosch.
Togarashi	Red pepper	*Capsicum frutescens* L.
Hiyosu	Henbane	*Hyoscymus niger* L.
Chosen-asagawo	Jimson weed	*Datura Stramonium* L. *Datura Tatula* L.
Kuko	Matrimony vine	*Lycium chinense* Mill.
Senkiu	————	*Cnidium officinale* Makino
Toki	————	*Ligusticum acutilobum* Sieb. et Zucc.
Bofu	————	*Siler divaricatum* Bent. et Hook. f.
Uikio	Fennel	*Foeniculum vulgare* Hill.
Yoroi-gusa	————	*Angelica glabra* Makino
Kanokoso	Common valerian	*Valeriana officinalis* L.
Shoga	Ginger	*Zingiber officinale* Rosc.
Gajutsu	Long zedoary	*Curcuma zedoaris* Rosc.
	V. Fiber Crops	
Riuzetsu-ran	Century plant	*Agave americana* L.
Shizaru-asa	Sisal hemp	*Agave rigida* Mill.
Hechima	Rag gourd	*Luffa cylindrica* Roem.
Ine	Rice	*Oryza sativa* L.
Niusai-ran	New Zealand flax	*Phorimium tenax* Forst.
Ama	Flax	*Linum usitatissimum* L.
Wata	Cotton	*Gossipium herbaseum* L. *Gossipium hirsutum* L.
Ichibi	Indian mallow	*Abutilon avicennae* Gaertn.
Asa	Hemp	*Cannabis sativa* L.
Ito-basho	————	*Musa liukiuensis* Makino
Tsunaso	Jute	*Corchorus capsularis* L.
Karamushi	Ramie	*Boehmeria nivea* Gaug.
	VI. Brush and Broom Crops	
Hokigi	Summer cypress	*Kochia scoparia* Schrad.
Rashakaki-gusa	Teasel	*Dipsacus fullonum* L.
Hoki-morokoshi	Broom corn	*Holcus Sorghum* L. var. *technicus* Bailey
Karukaya	————	*Themeda triandra* Forsk. var. *japonica* Makino
Shuro	Hemp palm	*Trachycarpus excelsa* Wendl.
	VII. Mat Crops	
Shichito	————	*Cyperus malaccensis* Lam.
Kasa-suge	————	*Carex dispalata* Boott
Futo-i	————	*Scirpus Tabernasmontani* Gmel.
Kwanso	————	*Cyperus Iwasakii* Makino
Sankaku-i	Chair-makers' rush	*Scirpus triqueter* L.
Ampera-i	Chinese mat rush	*Lepironia mucronata* Rich.
Ine	Rice	*Oryza sativa* L.

TABLE 1.—*Continued*

Common Japanese name	Common English name (if any)	Scientific name
	VII. Mat Crops—*Cont.*	
Kita-yoshi	———	*Phragmites communis* Trin.
I	Mat rush	*Juncus effusus* L. var. *decipiens* Buch.
Gama	Common cattail flag	*Typha latifolia* L.
	VIII. Plait and Wicker Crops	
Omugi	Barley	*Hordeum vulgare* L.
Kori-yanagi	Osier	*Salix purpurea* L.
	IX. Oil Crops	
Aburana	Rape	*Brassica Napus* L.
Karashina	Mustard	*Brassica alba* Rabenh.
		Brassica nigra Koch
Togoma	Castor bean	*Ricinus communis* L.
Abura-giri	Wood oil tree	*Aleurites cordata* Steud.
Egoma	———	*Perilla ocimoides* L. var. *typica* Makino
Daizu	Soybean	*Glycine Max* Merr.
Nankin-mame	Peanut	*Arachis hypogaea* L.
Wata	Cotton	*Gossipium herbaceum* L.
Oriibu	Olive	*Olea europaea* L.
Goma	Sesame	*Sesamum orientale* L.
Tsubaki	Camelia	*Camellia japonica* L. var. *hortensis* Makino
Sazanka	Lady Bank's camelia	*Camellia Sasanqua* Thunb.
	X. Wax Crops	
Haze	Japanese waxtree	*Rhus succedanea* L.
	XI. Lacquer Crops	
Urushi	Lacquer tree	*Rhus vernicifera* DC.
	XII. Tannin Crops	
Mame-gaki	Date plum	*Diospyros Lotus* L.
	XIII. Paper Crops	
Tsuso	———	*Tetrapanax papyriferum* Koch
Embaku	Oats	*Avena sativa* L.
Kozo	Paper mulberry	*Broussonetia Kazinoki* Sieb.
Mitsumata	———	*Edgeworthia papyrifera* Sieb. et Zucc.
Gampi	———	*Wikstroemia sikokiana* Franch. et Sav.
	XIV. Paste Crops	
Konniaku	———	*Amorphophallus Konjak* C. Koch
Satsuma-imo	Sweet potato	*Ipomoea Batatas* Lam.
Komugi	Wheat	*Triticum aestivum* L.
Tororo-awoi	———	*Hibiscus Manihot* L.
Jaga-imo	Potato	*Solanum tuberosum* L.
	XV. Dye Crops	
Yama-ai	Assam indigo	*Strobilanthea flaccidifolius Nees*
Murasaki	Graymile	*Lithospermum officinale* L.
Benibana	Sunflower	*Carthamus tinctorius* L.
Taisei	———	*Isatis oblongata* DC.
Ki-ai	Indigo	*Indigofera tinctoria* L.
		Indigofera Anil L.
		Indigofera Arrecta Hoehst.
Yama-momo	———	*Myrica rubra* Sieb. et Zucc.
Binro	Areca palm	*Areca Catechu* L.
Ai	Chinese indigo	*Polygonum tinctorium* Lour.
Kuchinashi	Cape jasmine	*Gardenia jasminoides* Ellis

TABLE 1.—*Concluded*

Ukon	Turmeric	*Curcuma longa* L.
Kio-o	Wild turmeric	*Curcuma aromotica* Salisb.
	XVI. Stimulant and Narcotic Crops	
Nemu-cha	———	*Cassia mimosoides* L. var. *nomame* Makino
Ebisu-gusa	Wild senna	*Cassia Tora* L.
Binro	Areca palm	*Areca Catechu* L.
Keshi	Opium poppy	*Papaver somniferum* L.
Kimma	Betel pepper	*Piper Belle* L.
Kohi	Common coffee	*Coffea arabica* L.
Tabako	Tobacco	*Nicotiana Tabacum* L.
Cha	Tea	*Thea sinensis* L.
	XVII. Perfumery Crops	
Kosui-gaya	Citronella grass	*Cymbopogon Nardus* Rendle.
	XVIII. Brewery Crops	
Satsuma-imo	Sweet potato	*Ipomoea Batatas* Lam.
Koke-momo	Mountain cranberry	*Vaccinium Vitis*-Idaea L.
Ine	Rice	*Oryza sativa* L.
Omugi	Barley	*Hordeum vulgare* L.
Awa	Foxtail millet	*Setaria italica* Beauv.
To-morokoshi	Maize	*Zea Mays* L.
Morokoshi	Grain sorghum	*Holcus Sorghum* L. var. *caffronum* Bailey
Jaga-imo	Potato	*Solanum tuberosum* L.
Budo	Grape	*Vitis* spp.
	XIX. Manurial Crops	
Daikon	Oriental radish	*Raphanus sativus* L. var. *longipinnatus* Bailey
Sotetsu	Sago palm	*Cycas revoluta* Thunb.
Genge	Milk vetch	*Astragalus sinensis* L.
Umagoyashi	Toothed bur clover	*Medicago hispida* Gaertn.
Daizu	Soybean	*Glycine Max* Merr.
Sora-mame	Broad bean	*Vicia Faba* L.
Endo	Pea	*Pisum sativum* L.
Yaenari	Mung bean	*Phaseolus aureus* Roxb.
Densei	Egyptian sesban	*Sesbania aegyptiana* Pers.
Hata-sasage	Catjang	*Vigna Catjang* Walp.
Yahazu-endo	Common vetch	*Vicia sativa* L.
Ke-yahazu-endo	Hairy vetch	*Vicia villosa* Roth.
Aka-tsumekusa	Red clover	*Trifolium pratense* L.
Tsuno-umagoyashi	Serradella	*Ornithopus sativus* Brot.
Hauchiwa-mame	Yellow lupine	*Lupinus luteus* L.
Hassho-mame	Yokohama bean	*Stizolobium Hasjoo* Piper et Tracy
Kibana-hagi	———	*Crotalaria striata* DC.
Kimame	Pigeon pea	*Cajanus Cajan* Millsp.

Summing up the material presented in Table 1, Table 2 has been prepared to show at a glance the number of crop plants, together with that of species and varieties, belonging to the respective divisions.

It will be noted from Table 2 that the number of food crop plants, as well as that of the respective species and varieties, does not correspond to the sum of numbers due to eight subdivisions within it, for, as already mentioned, there are some plants which spread over more than two subdivisions, whereas in groups other than food crops this

TABLE 2.—*Summary of crop plants listed in Table 1.*

Classification	Number of crop plants	Number of species and varieties
I. Food crops	206	220
1. Grain crops	30	30
a. Cereal crops	12	12
b. Legume crops	14	14
c. Miscellaneous grain crops	4	4
2. Root crops	16	16
3. Subterranean stem crops	15	15
4. Aerial stem crops	10	10
5. Leaf crops	47	48
6. Flower crops	8	7
7. Fruit crops	85	99
a. Vegetable fruit crops	25	28
b. Non-vegetable fruit crops	60	71
8. Mushroom crops	4	4
II. Relish crops	30	31
1. Aromatic crops	17	17
2. Pungent crops	9	10
3. Sour crops	2	2
4. Sugar crops	2	2
III. Forage crops	40	42
1. Gramineous crops	20	20
2. Leguminous crops	10	10
3. Miscellaneous forage crops	10	12
IV. Medical crops	57	58
V. Fiber crops	12	13
VI. Brush and broom crops	5	5
VII. Mat crops	10	10
VIII. Plait and wicker crops	2	2
IX. Oil crops	12	13
X. Wax crops	1	1
XI. Lacquer crops	1	1
XII. Tannin crops	1	1
XIII. Paper crops	5	5
XIV. Paste crops	5	5
XV. Dye crops	11	13
XVI. Stimulant and narcotic crops	8	8
XVII. Perfumery crops	1	1
XVIII. Brewery crops	9	10
XIX. Manurial crops	18	18

is not the case. This should also be taken into consideration in calculating from these data the total number of crop plants grown in Japan. Taking this into account, it will be observed that there are 365 crop plants and 386 species and varieties listed.

The writer does not regard this study complete in any sense, for he believes that there are probably other plants which have been overlooked.[3] It is possible that the number of crop plants in Japan may be less as compared with that of many American and European countries, which might be attributed to the fewer kinds of forage plants grown in Japan owing to the scarcity of livestock.

[3]Some 10 or more crop plants which have come to the writer's attention since the preparation of this paper will be published later in a supplement to this report.

THE NITRIFICATION OF AMMONIUM SULFATE AS INFLUENCED BY SOIL REACTION AND DEGREE OF BASE SATURATION[1]

JAMES A. NAFTEL[2]

It has been well established that nitrification in soils occurs most rapidly under neutral or slightly acid conditions. In many soils, however, nitrification takes place at rather high H-ion concentrations (4, 5, 8, 12, 13, 15)[3]. These investigations show that active nitrification may occur in acid soils. Varied reasons are given for the favorable environment of the organisms in these soils. Observations indicate that the "critical reaction" for this process varies with different soils.

Nitrification has probably been studied more extensively than any other soil-biological activity. It is an exceedingly complex study when one considers that the physical and chemical conditions of the soil as well as biological activities are involved. A considerable amount of work by different investigators shows conflicting results as to the optimum conditions for nitrification in soils. Waksman (14) discussed several factors which influence this process. He has pointed out the fact that there has been little attempt to study nitrification as influenced by the initial and final reaction of soils. Most investigators have attempted to study nitrification in relation to the lime requirement of soils rather than their H-ion concentration. Additions of lime have been suggested (1) for use in nitrification studies to neutralize the acidity produced, but, as shown by Hutchinson and MacLennan (7), lime (CaO) causes a partial sterilization of the soil. The lime requirement procedure very often gives conflicting results because it may indicate either a high acidity or a high buffer capacity. These conditions have opposite effects on nitrification.

The amounts of ammonium sulfate used in nitrification studies have varied with each investigator. Interesting results on this point are shown by Harper and Boatman (6). The amounts which have been used vary from 0.1 to 1.0 gram of ammonium sulfate per 100 grams of soil which are equivalent to 2,000 and 20,000 pounds per acre, respectively. Smaller quantities are desirable because (a) they come nearer duplicating field conditions, (b) nitrification is more

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication November 6, 1930.

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[3]Reference by number is to "Literature Cited," p. 184.

complete, (c) acidity produced is less, (d) change in reaction is smaller, and (e) fewer dilutions are necessary in the determination of nitrates.

In considering the previous investigations on nitrification, it seemed that there should be a correlation between the degree of base saturation and nitrification since in highly buffered soils high nitrification occurred (9, 13). The objects of this investigation were to study (a) the influence of reaction and degree of base saturation of soils on nitrification, and (b) the relationship of nitrification to plant growth.

EXPERIMENTAL

Five soils of widely different fertility, texture, and degree of weathering were selected for this study. These soils were brought to approximately pH 4.0, 5.0, 5.5, and 6.5 by adding H_2SO_4 or $CaCO_3$. The soils used are given in Table 1, and the amounts of N/1 H_2SO_4 or $CaCO_3$ required to bring the soil to the reactions indicated above are shown in Table 2. The reactions were adjusted by adding the dilute acid or lime to 2,000 grams of soil in a shallow pan, thoroughly mixing and storing under optimum moisture conditions until equilibrium was established. In order to determine whether or not equilibrium had been reached samples were taken and leached and the pH values determined by using the quinhydrone electrode. After equilibrium was established, the soils were leached to remove the soluble salts.

Six 200-gram samples of each soil were weighed into tumblers. Three of the samples were used as controls, and to each of the other three 40 mgms of $(NH_4)_2SO_4$ in solution were added. These were incubated at 25° to 28° C under optimum moisture conditions. The moisture lost by evaporation was replaced at weekly intervals.

The NO_3 content and pH value of the soils were determined after 10-, 20-, and 30-day incubation periods by using the phenoldisulfonic acid and colorimetric methods, respectively. The clear extract was obtained by the use of collodion bags as described by Pierre and Parker (11). Base saturation, exchange capacity, and exchangeable cations were determined by the method of Conrey and Schollenberger (3). Exchangeable Ca was determined in the ammonium acetate leachings and also by the electrodialysis method described by Bradfield (2).

The soils used in the study varied in chemical and physical composition (Table 1) and also in nitrification of $(NH_4)_2SO_4$. Results of the nitrification studies are presented in Figs. 1 to 5, inclusive. Pierre (10) pointed out that the percentage base saturation of these soils

In assembling the material for two articles by James A. Naftel, one appearing in the February number and one in the March number of this Journal, the illustrations were interchanged. The figures printed herewith should accompany the article on ammonium and nitrate nitrogen absorption published on pages 142 to 158 of the February number.—THE EDITOR.

FIG. 1. Cotton grown in solutions A, C, and E for 3 weeks.

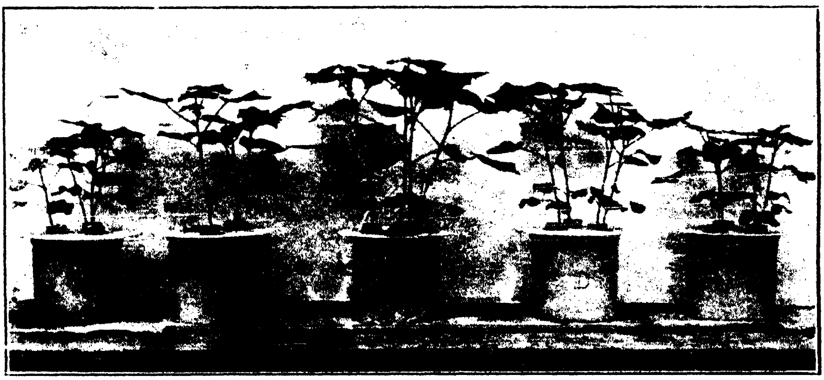

FIG. 2. Cotton grown in solutions A, B, C, D, and E for 6 weeks.

FIG. 3.—Cotton grown in solutions A, B, C, D, and E for 9 weeks.

FIG. 4.—Cotton grown in solutions A, C, and E for 11 weeks.

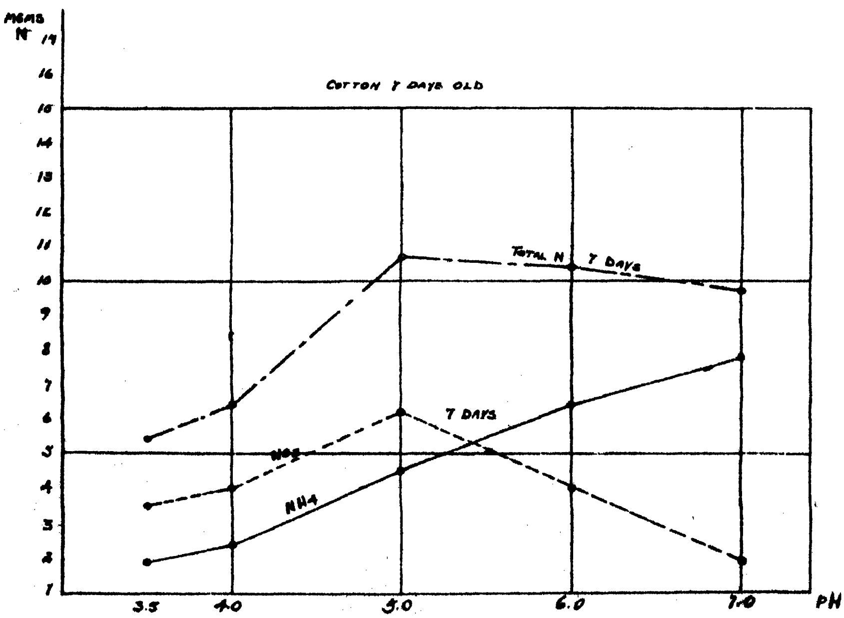

FIG. 5.—The absorption of NH_4- and NO_3-N at varying reactions.

correlated very well with plant growth. The growth of corn, barley, and sorghum (Table 3) at approximately the same pH values as were used in the nitrification studies gave results which indicate a correlation between this biological activity and plant growth. The reaction of a given soil determines to a great extent its percentage base saturation (Table 4).

TABLE 1.—*Classification and description of soils used in nitrification studies.**

Soil No.	Soil type	Geologic classification of soils	H-ion concentration, pH	Organic matter, organic C x 1.724	Mols SiO_2 / Mols R_2O_3 of colloids
672	Cecil sandy loam, South Carolina	Residual, Piedmont Plateau	5.88	3.48	1.78
673	Delta light silt loam, Mississippi	Alluvial from Mississippi River	6.60	1.48	2.66
674	Cecil clay loam, Alabama	Residual, Piedmont Plateau	6.15	1.57	1.57
675	Norfolk sandy loam, Alabama	Marine Coastal Plain	5.60	0.97	1.92
683	Susquehanna fine sandy loam, Alabama	Marine Coastal Plain	5.40	2.47	2.01

*Data taken from Pierre (10).

TABLE 2.—*The amounts of N/1 H_2SO_4 and $CaCO_3$ added to 1 kilogram of soil and the pH values obtained.*

Soil No.	N/1 H_2SO_4	pH	N/1 H_2SO_4	pH	N/1 H_2SO_4	pH	$CaCO_3$	pH
	cc		*cc*		*cc*		*grams*	
672	58.0	4.28	23.0	5.12	5.0	6.10	1.5	7.55
673	52.0	4.08	25.0	5.48	16.5	5.95	0.0	7.33
674	62.0	4.20	20.0	5.50	10.0	5.80	0.8	6.70
675	20.0	4.10	5.0	5.35	0.0	6.35	0.7	7.10
683	35.0	3.75	9.0	4.90	2.0	5.58	1.5	6.84

SOIL 672, CECIL SANDY LOAM (FIG. 1)

There was no nitrification of the $(NH_4)_2SO_4$ nor of the soil nitrogen at pH 4.4 during the incubation periods used. Very little biological activity, apparently, occurred at this reaction, as was further evidenced by a small plant growth at pH 4.8 (Table 3). This soil was only 17.5% saturated with bases at pH 4.4 and Ca constituted only 64% of the total. At pH 5.2 and 39.8% saturated with bases, 15, 32, and 66% of the $(NH_4)_2SO_4$ nitrified after incubation periods of 10, 20, and 30 days, respectively. Crop yields were high at this reaction. Nitrification increased considerably at pH 5.6, 66.5% of the

TABLE 3.—*The growth of corn, sorghum, and barley at different pH values.**

Soil No.	Corn		Sorghum		Barley	
	pH before corn	Yield in grams	pH before sorghum	Yield in grams	pH before barley	Yield in grams
672	4.80	14.3	4.80	5.2	4.80	6.5
	5.13	16.9	4.93	23.9	5.08	13.4
	5.25	16.8	5.08	32.4	5.30	25.5
	5.88	17.9	5.60	29.2	5.78	17.7
	6.63	15.7	6.50	30.6	6.35	18.8
673	5.00	30.4	4.60	49.3	4.60	22.5
	5.23	33.1	4.78	51.7	4.75	20.4
	5.50	35.0	4.85	49.7	4.83	20.7
	6.60	25.2	5.80	50.9	5.65	25.2
	6.83	27.0	6.55	48.7	5.95	19.3
674	4.73	11.6	4.75	19.2	4.80	7.1
	4.83	14.3	4.85	26.3	4.95	10.0
	4.98	15.7	4.95	32.1	5.05	16.8
	6.15	13.5	5.80	27.9	5.83	17.8
	6.80	13.3	6.78	23.1	6.60	19.0
675	4.73	5.1	4.75	0.4	4.75	1.3
	4.90	8.6	4.93	0.7	4.90	1.1
	5.05	11.4	5.03	6.8	5.18	11.9
	5.60	12.9	5.40	20.6	5.60	9.1
	6.58	13.5	6.43	26.9	6.20	14.2
683	—	—	4.80	28.4	4.65	13.5
	—	—	4.85	28.5	4.88	17.1
	—	—	5.00	29.9	5.18	21.3
	—	—	5.40	34.6	5.35	19.2
	—	—	6.20	25.2	6.00	21.3

*Data taken from Pierre (10).

TABLE 4.—*Percentage base and calcium saturation and percentage calcium of total bases.*

Soil No.	Percentage base saturation				Percentage Ca saturation				Percentage Ca of bases			
	pH 4.0	pH 5.0	pH 5.5	pH 6.5	pH 4.0	pH 5.0	pH 5.5	pH 6.5	pH 4.0	pH 5.0	pH 5.5	pH 6.5
672	17.5	39.8	47.8	69.3	11.2	19.7	32.6	60.0	63.9	49.5	68.3	86.5
673	46.0	58.5	61.0	62.5	41.3	52.5	55.0	56.2	90.0	90.0	90.0	90.0
674	21.2	42.1	42.1	50.8	19.1	33.1	35.5	63.2	90.0	78.5	88.0	—
675	23.2	47.7	63.2	96.7	7.6	27.6	37.5	72.5	32.6	58.0	59.2	75.0
683	23.5	32.3	37.8	61.2	20.8	22.2	27.8	66.2	85.8	70.0	75.8	—

$(NH_4)_2SO_4$ having nitrified after 10 days, 92.8% after 20 days, and 100% after 30 days. Similar results were obtained at pH 6.7, except that slightly more $(NH_4)_2SO_4$ nitrified during the 10-day period.

As would be expected, the percentage base saturation and percentage Ca saturation increased with the pH values. These results indicate that the "critical reaction" for nitrification in this soil is between pH 4.0 and 5.0 and that the optimum reaction is not lower than pH 5.6.

SOIL 673, DELTA LIGHT SILT LOAM (FIG. 2)

At pH 4.1 the original nitrogen in the soil nitrified to a great extent, whereas only 7.8% of the $(NH_4)_2SO_4$ nitrified during 10 days. It will be noticed (Table 4) that this soil was 46% saturated with bases and 41% saturated with Ca. Plant growth was very

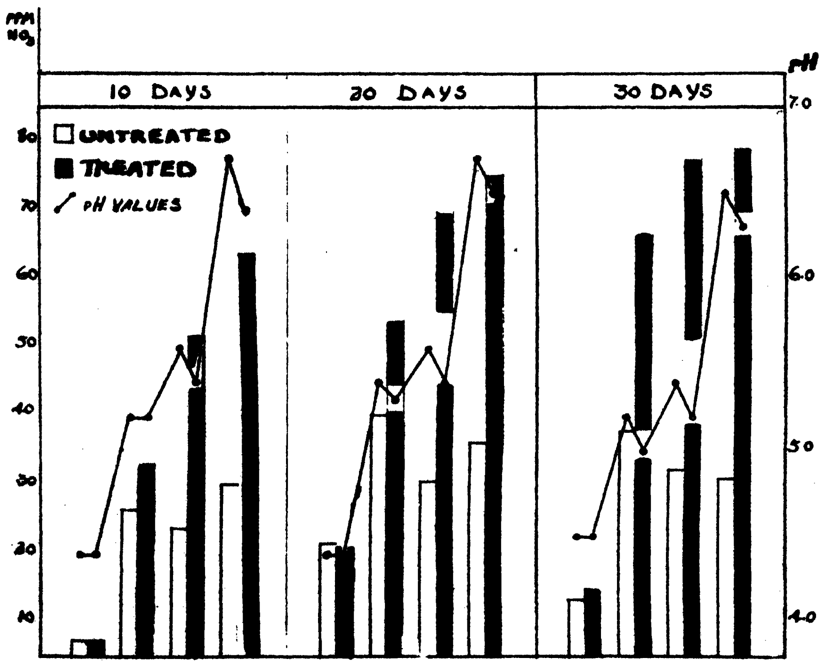

FIG. 1.—Nitrification of ammonium sulfate at different reactions in soil 672.

good at this low reaction. There was a slight decrease in NO_3 at 20 and 30 days' incubation in the treated and untreated soil. A very high accumulation of NO_3 from the soil nitrogen occurred at pH 5.5, but there was no nitrification of $(NH_4)_2SO_4$. Considerable nitrification of $(NH_4)_2SO_4$ took place at pH 5.95, but the accumulation of NO_3 was lowest at this reaction. The high accumulation of NO_3 probably accounts for the decreased nitrification at 20 and 30 days' incubation.

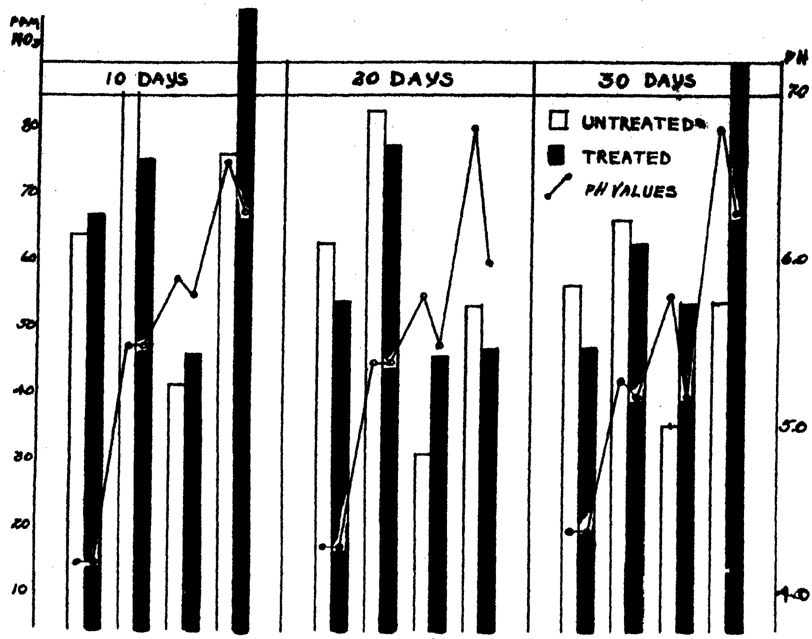

FIG. 2.—Nitrification of ammonium sulfate at different reactions in soil 673.

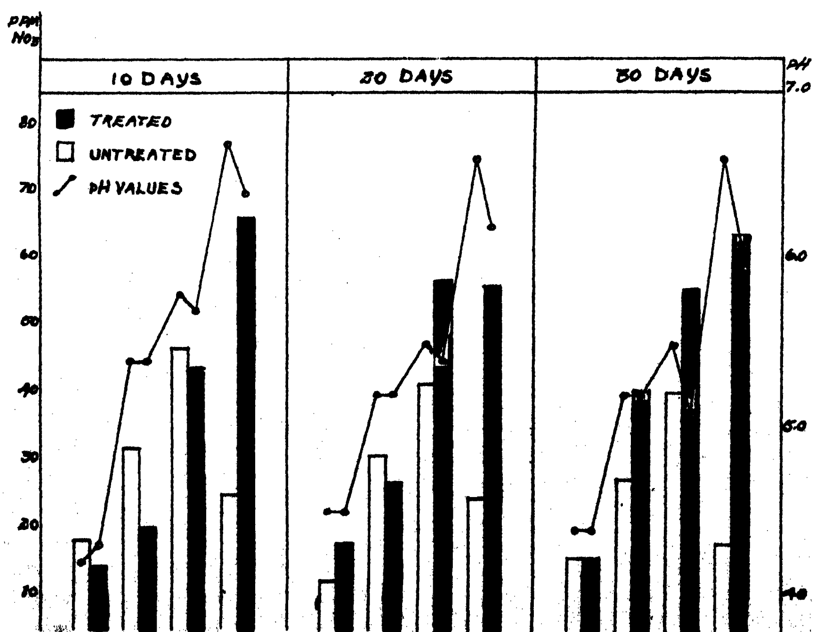

FIG. 3.—Nitrification of ammonium sulfate at different reactions in soil 674.

SOIL 674, CECIL CLAY LOAM (FIG. 3)

Nitrification processes were evident at pH 5.2 At the end of the 10-day period the NO_3 produced was 7.8% higher in the untreated soil than in that which received $(NH_4)_2SO_4$. During the 20-day period only 12.3% of the added NH_3 nitrified when the reaction was approximately pH 4.2, and after 30 days the NO_3 in the treated and untreated soil was equal. No $(NH_4)_2SO_4$ nitrified in the 10-day period, except at pH 6.7. This soil was only 21.2, 42.1, and 42.1% saturated

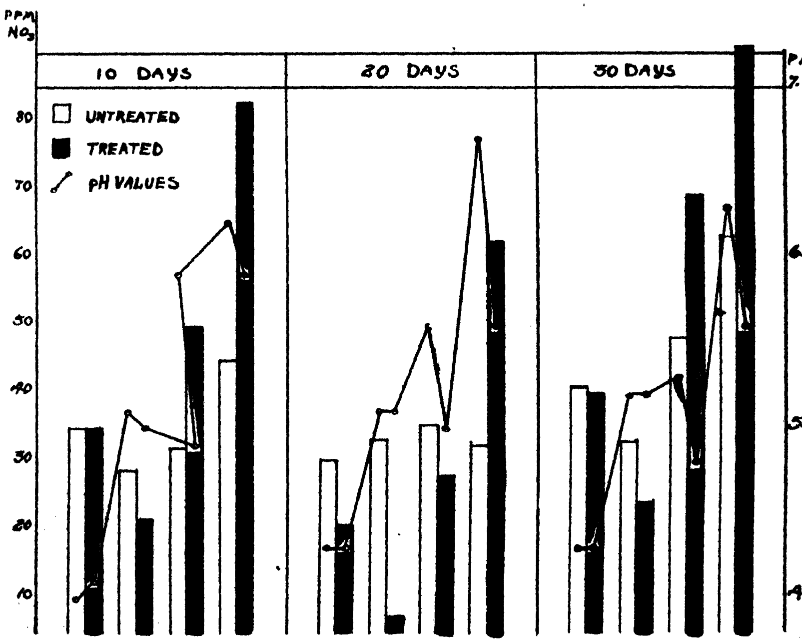

FIG. 4.—Nitrification of ammonium sulfate at different reactions in soil 675.

with bases at pH 4.2, 5.4, and 5.8, respectively. Addition of $(NH_4)_2SO_4$ decreased nitrification during the 10- and 20- day periods, but after 30 days of incubation 20.2% of the added nitrogen had nitrified. Ninety-seven per cent of the $(NH_4)_2SO_4$ nitrified within 10 days at pH 6.7, and the soil was 63% saturated with Ca. The "critical reaction" for the nitrification of $(NH_4)_2SO_4$ was between pH 4.2 and 5.4. The optimum reaction for nitrification of the soil N was pH 5.8.

SOIL 675, NORFOLK SANDY LOAM (FIG. 4)

There was no nitrification of $(NH_4)_2SO_4$ at pH 4.0 during the periods of incubation. Considerable NO_3, however, was formed from the soil N. Nitrification at pH 5.1 was decreased by the ad-

dition of $(NH_4)_2SO_4$. The soil was only 7.6 and 27.6% saturated with Ca at pH 4.0 and 5.1, respectively. Forty-two per cent of the added N nitrified at pH 5.9 after being incubated for 10 days and 49.5% after 30 days. There was a decrease of 17% after 20 days' incubation. When the reaction was pH 6.2, 91.5% of the added N nitrified after 10 days. The soil was 72.5% saturated with Ca. The "critical reaction" for the nitrification of $(NH_4)_2SO_4$ was between pH 5.1 and 5.9 and the optimum reaction studied was pH 6.2.

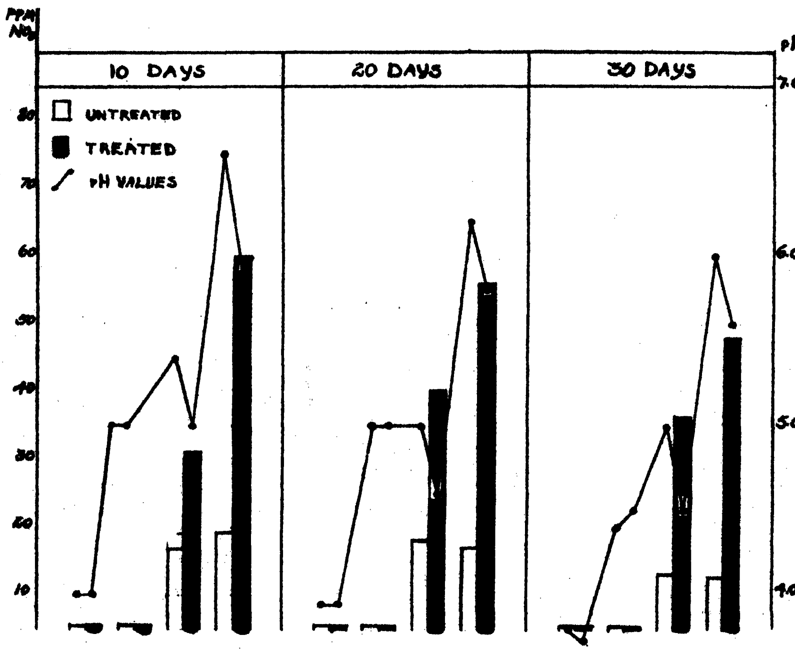

FIG. 5.—Nitrification of ammonium sulfate at different reactions in soil 683.

SOIL 683, SUSQUEHANNA FINE SANDY LOAM (FIG. 5)

No nitrification occurred in this soil at pH 3.7 or 4.9, and the percentage base and Ca saturation were low at these reactions. There were no plants grown below pH 4.8, but at this reaction good growth was obtained (Table 3). At pH 5.6 the added N nitrified to the extent of 33.5% after 10 days' incubation and 54.8% after 30 days. Nitrification of the $(NH_4)_2SO_4$ increased to 96.2% at pH 6.8, after the 10-day incubation period. At this reaction the soil was 66.2% saturated with Ca.

DISCUSSION

Base exchange studies (Tables 4 and 5) indicated a relationship between the percentage base and Ca saturation and nitrification of $(NH_4)_2SO_4$. After 10 days' incubation there was no nitrification of $(NH_4)_2SO_4$ at a reaction of approximately pH 4.0 in any of the soils studied, except in soil 673. In this case only a small amount nitrified and the soil was 41.3% saturated with Ca. The other soils at this reaction contained not more than one-half as much replaceable Ca as soil 673. Since there was no oxidation of the added nitrogen at pH 4.0, the reaction of the soils did not change after 30 days' incubation.

The soils at approximately pH 5.0 showed an increase in nitrification of the soil nitrogen in all cases, except soil 683. This soil was low in replaceable Ca. The only change in reaction occurred in soil 672, which may be accounted for by the fact that there was a high NO_3 accumulation at this reaction. The percentage base saturation was practically doubled by a change in pH from 4.0 to 5.0, except in soil 673. In this case it increased but slightly.

TABLE 5.—*Base exchange data of soils studied.*

Soil No.	Milligram equivalents						
		pH 4.0			pH 5.0		
	Ex-change capacity	Ex-change H	Ex-change bases	Ex-change Ca	Ex-change H	Ex-change bases	Ex-change Ca
672	8.97	7.40	1.57	1.01	5.40	3.57	1.96
673*	11.80	6.40	5.40	4.88	4.90	6.90	6.20
674	6.92	5.45	1.47	1.33	4.00	2.92	2.30
675	2.61	2.00	0.61	0.20	1.36	1.25	0.72
683*	7.30	5.59	—	1.52	4.94	—	1.62
683†	—	—	1.72	1.48	—	2.36	1.65

Soil No.	Milligram equivalents						
		pH 5.5			pH 6.5		
	Ex-change capacity	Ex-change H	Ex-change bases	Ex-change Ca	Ex-change H	Ex-change bases	Ex-change Ca
672	8.97	4.71	4.26	2.92	2.77	6.20	5.39
673*	11.80	4.60	7.20	6.48	4.40	7.40	6.64
674	6.92	4.00	2.92	2.66	3.40	3.52	4.00
675	2.61	0.96	1.65	0.98	0.08	2.53	1.90
683*	7.30	4.54	—	2.04	2.82	—	4.84
683†	—	—	2.76	2.10	—	4.48	—

*H and bases calculated from Ca data and total exchange capacity.
†Dialysis method.

Nitrification did not occur in soil 683 until the soil had a reaction of pH 5.5. This was probably due to the low Ca saturation of this soil at the low pH values. There were considerable increases in H-ion concentration, due to nitrification, in all of the treated soils at pH 5.5. All soils had a higher percentage nitrification of $(NH_4)_2SO_4$ at the highest pH values used (approximately 6.5). At this reaction the soils contained a higher percentage base and Ca saturation than at the other pH values studied. In most cases plant growth was better at pH 6.5 than at the very acid reactions (Table 3). This may be due to the fact that more Ca would be available for the plants at the higher pH values or that nitrification occurred at a more rapid rate, thereby supplying the plants with more NO_3.

It was thought that soil 673 might contain a strain or strains of micro-organisms which could endure high acidity, since nitrification proceeded in the most acid cultures. Soil 683 was inoculated with a small quantity of soil 673, but nitrification did not occur.

SUMMARY

Nitrification of $(NH_4)_2SO_4$ was studied using five soils that differed widely in percentage base and Ca saturation at similar pH values. A summary of the results of this study follows.

1. After 10 days' incubation, nitrification of $(NH_4)_2SO_4$ occurred at pH 4.1 only in the soil which had a high percentage base and Ca saturation. In soils having a lower base saturation, nitrification of $(NH_4)_2SO_4$ did not occur at this reaction during the same period.
2. Nitrification varied considerably in different soils at similar reactions.
3. Differences other than base saturation and reaction appear to be very important in the process of nitrification at low reactions.
4. These nitrification studies show a fairly good correlation with the plant growth data as found by Pierre on these same soils at various pH values.
5. Nitrification increased with the percentage base and Ca saturation.

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A MODIFICATION OF DELWICHE'S SYSTEM OF LAYING OUT CEREAL VARIETY TEST PLATS[1]

K. H. KLAGES[2]

Variety test plats of cereals are usually separated by cultivated alleys. Such alleys not only require varying amounts of cultivation to keep them free of weeds, but are also, as would be expected due to the greater amounts of moisture and nutrients available to the plants of the outside drill rows of the plats, the cause of a considerable border effect. This is true especially in places where the availability of moisture is the main limiting factor to crop production, such as is the case in semi-arid sections or even during dry seasons in humid sections. Yet it is convenient to have variety test plats definitely delineated. Where cultivated alleys are used, two outside drill rows on either side of the plats may be cut out previous to harvest in order to eliminate or at least to reduce the disturbing border effect. This requires, however, a great amount of hand labor. Due to the cost involved, the border rows of plats are frequently not removed. As a result, the yields reported from such tests are higher than would be obtained under comparable field conditions. Since the plant breeder is, in most instances, concerned more with the comparative yielding abilities of the strains tested than with their actual field yields, this in itself would not constitute a great source of error were it not for the fact that different strains may react quite differently to the influence of the cultivated border.

Previous to 1930 variety test plats at the South Dakota Agricultural Experiment Station were separated by cultivated alleys. Border effects, especially in dry seasons, were very pronounced. In extreme drought years at the Highmore sub-station the only grain produced was found along the cultivated alleys. In the spring of 1930, a modification of the plan reported on by Delwiche[3] was adopted. The results were so gratifying from the standpoints of eliminating the need of cultivation of alleys and the difficulties incident to such a method of handling plats, as well as not making it necessary to cut border rows, as to merit reporting at this time.

The plan used is presented graphically in Fig. 1. It differs from Delwiche's plan in that only two rather than six drill rows were grown

[1]Contribution from the Department of Agronomy, South Dakota Agricultural Experiment Station, Brookings, S. Dak. Received for publication November 10, 1930.

[2]Associate Agronomist, in charge of Cereal Breeding.

[3]DELWICHE, E. J. A new system for variety test plats. Jour. Amer. Soc. Agron., 20: 771–773. 1928.

in the alleys between plats. As in Delwiche's plan, the plats are marked on either side by a blank drill row. The machines used for seeding the wheat, oats, barley, and flax variety test plats at Brookings and Highmore were 14-disk drills with a distance of 6 inches between the drill rows. The two cups next to the outside of the drills were closed making the plats 10 drill rows wide. The two outside drill holes plant the same variety as is being sown on the plat. This provides a border of one drill row of the same variety for each plat. The width of the plats for the purpose of calculating yields was

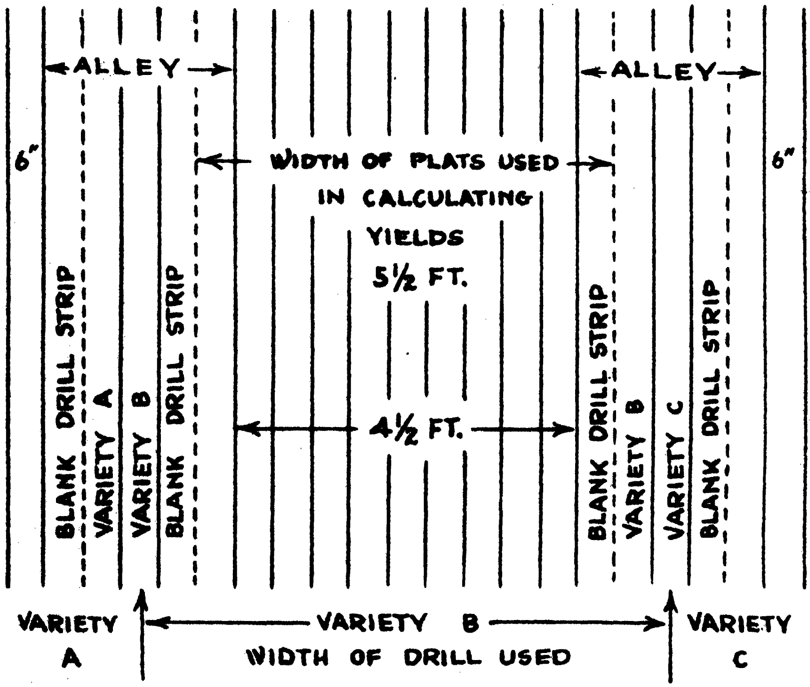

FIG. 1.—Diagram of variety test plats used. Note that the respective plats are delineated by blank drill rows and that each one of the two drill rows in the planted alley is of the same variety as the plats they adjoin.

figured from the middle of the two respective blank strips on either side. This made the plats 5½ feet wide with the type of drills used. Since the plats were 132 feet in length after being trimmed down at the ends, the area was exactly 1/60 of an acre. The distance between the two outside drill rows of the plats was of course only 4½ feet, a good width to be harvested with a 5-foot binder. The alleys figured from the two outside rows of adjacent plats were 2½ feet wide. This width proved to be great enough for South Dakota conditions. A 3-foot alley could be provided for by increasing the

distance between the two rows in the alley from 6 inches to 1 foot. Under conditions where a greater vegetative growth is common this may be a desirable modification. It is assumed that the plants of the two outside rows of the plats will use up half of the moisture and nutrients of the blank border. The border strips were not cultivated. No difficulty was encountered with weeds, since the space left blank, being only 1 foot wide, was shaded effectively enough to discourage their growth.

The blank strips between the plats and the rows in the alleys were not wide enough to produce any border effects. Fig. 2 shows the appearance of the barley variety test plats at Highmore. No border

FIG. 2.—Looking down the two rows grown in the alley between adjacent plats in the barley variety test field at Highmore, 1930.

effects could be detected. The same good results were obtained in the case of common spring wheat, durum wheat, oats, barley, and flax variety test plats at Brookings and Highmore even with a dry season favoring a greater amount of growth in border rows.

Attention is called to the fact that each one of the two rows in the alley are of the same variety as the plats they adjoin, thus reducing the danger of mixtures during harvesting operations. If any varietal competition takes place between adjacent varieties, it will occur between the two rows in the alleys without disturbing the yields of the plats.

In humid sections with climatic conditions more conducive to greater straw growth and consequent greater danger of lodging, the

plan advocated by Delwiche with four to six drill rows, two or three as the case may be of each adjacent variety, being grown in the alley, may be more practical than the method here described. Its disadvantage is that a much larger proportion of the area devoted to the test is occupied by border rows. This results not only in less economical utilization of the land available, but since it becomes necessary to spread the test over a larger area the investigator stands the risk of increased soil heterogeniety. Under South Dakota conditions no difficulties were encountered in harvesting the plats such as outlined with a 5-foot binder. The alleys were cut out after the plats were harvested. The width of plats must of course be adjusted to the type of machines available for seeding and harvesting. The plan presented here would work equally well with a 16-disk drill and a 6-foot binder. This would allow for plats 12 drill rows wide. It is desirable of course to have the plats of a width so that they may be cut with one swath of the binder. A 12-disk drill would make the plats rather narrow for best results. In case of lodging it may be necessary to cut out by hand the two rows in the alleys. Lodging is not, however, of common occurrence in regions with limited amounts of rainfall. It is in such regions that the method described above seems to be best adapted.

SUMMARY

Delwiche's plan for laying out cereal variety test plats was modified so that only two rather than six drill rows were grown in the alleys between adjacent plats.

The modified plan was found practical for South Dakota conditions in so far as it eliminated the necessity of cultivated alleys between plats, cut down border effects, and reduced the possibilities of exaggerated yields.

THE CHEMICAL COMPOSITION OF *AMBROSIA TRIFIDA* AT SUCCESSIVE GROWTH STAGES[1]

R. B. DUSTMAN AND L. C. SHRIVER[2]

From the standpoint of possible future economic value a knowledge of the chemical nature of many of our native wild plants is desirable. This is especially true of certain species which, for one reason or another, suggest themselves as worthy of attention. Thus certain of our wild grasses, although of inferior pasture value, are nevertheless so abundant and so widespread as to merit consideration. Forage plants of high protein content are usually regarded with favor by the feeder. In a brief period of 25 years white sweet clover (*Melilotus alba*) has passed from the status of a generally ignored plant or despised weed to that of a much-sought-after crop with a strong tendency to revolutionize the cropping systems of certain localities. Also, in these later days of development and expansion in the chemical industries, we seem justified in learning not only what plants will provide foodstuffs suitable for the immediate use of man or beast, but also those which will produce the greatest yields per acre of carbohydrates, protein, oil, or cellulose in the crude form to be worked over later into finished products by the industrial chemist.

Because of the fact that, while yet green and non-woody, it is readily eaten by farm animals, *Ambrosia trifida*, locally known as horseweed, kinghead, and giant ragweed, has attracted the attention of farmers for many years. A brief survey of the literature shows a few analyses of this species, all of them applying to single samples and thus indicating the composition of the plant at one particular stage only. Tracy (5)[3] in 1895, reported a single analysis from Mississippi. The following year, Peter (3) in Kentucky reported an analysis of plants gathered from the college campus at Lexington. Again, in 1903, Peter (4) gave a more complete analysis of plants grown from seed on the Station farm, "As an experiment to test the value of the plant for feeding." In this second report he states that, "The material is very nitrogenous and contains a large proportion of ash, carrying much potash. A young growth of the weeds plowed under ought to be very beneficial to the land." Ince (2) has reported analyses showing the content of ash and the common fertilizing constituents.

[1]Contribution from the Department of Agricultural Chemistry, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 93. Received for publication November 12, 1930.

[2]Head of Department and former Assistant, respectively.

[3]Reference by number is to "Literature Cited," p. 194.

PRESENT STUDY

These reports, together with statements of observations by farmers, led the writers to believe that a somewhat more systematic study of the plant at its various growth stages might be of value. Consequently, samples were chosen from plants growing wild at regular intervals throughout two successive seasons. During a third season the plants when first harvested were cut sufficiently high to permit a

TABLE 1.—*Time and stage of collecting samples.*

Date collected	Description
	1927 Samples
June 6...	Plants 12 to 24 inches high; stems 2 to 4 mm in diameter at base
July 6....	Plants 4 to 6 feet high; stems 10 to 15 mm in diameter at base; no flower clusters showing
Aug. 15..	Plants 6 to 10 feet high; stems 10 to 15 mm in diameter at base; in full bloom
Sept. 15..	Plants 6 to 10 feet high; stems 5 to 15 mm in diameter at base; leaves dead two-thirds way up stalks; seeds well formed, many in milk stage
Oct. 17...	Stalks only, 6 to 10 feet high, leaves fallen; plants matured, seeds partly fallen
	1928 Samples
June 7...	Plants 12 to 18 inches high; stems 2 to 3 mm in diameter at base
July 7....	Plants 2 to 4 feet high; stems 4 to 10 mm in diameter at base
Aug. 7...	Plants 5 to 7 feet high; stems 6 to 12 mm in diameter at base; flower clusters formed but before bloom
Sept. 7...	Plants 5 to 8 feet high; stems 6 to 15 mm in diameter at base; past full bloom, seeds partly formed
Oct. 8....	Plants 5 to 7 feet high; stems 5 to 10 mm in diameter at base; leaves dead but not fallen; seeds ripe and beginning to fall
	1929 Samples
June 10..	Plants 18 to 36 inches high; stems 4 to 10 mm in diameter at base; plants cut 6 to 10 inches high, leaving side branches for secondary growth
July 10...	2nd cutting; plants 2 to 4 feet high; stems 4 to 15 mm in diameter at base; cut several inches above old stubs of previous cutting (June 10)
July 10...	Tops only of plants 3 to 4 feet high; stems 4 to 12 mm in diameter at base; cut about 12 to 18 inches high to correspond with 2nd cutting above
	Miscellaneous Samples
July 6, 1927	Leaves only (with petioles) from plants similar to those described above for this date
July 7, 1928	Leaves only (with petioles) from plants similar to those described above for this date
June 10, 1929	Leaves only (with petioles) from plants similar to those described above for this date
Aug. 7, 1928	Single large plant very spreading in growth, 5 feet high; stalk 17 mm in diameter at base; spread of branches about 4½ feet across; flower clusters formed, but before bloom; location adjacent to regular sample collected on Aug. 7, 1928, described above

second growth to come on. This second growth also was sampled at a suitable time for comparison with the earlier growth.

In all three seasons samples were collected from plants growing on waste hillside land, the location being purposely changed from year to year. The three different seasons, therefore, represent three different locations, all hillside, with free competition by other species. Judging by the surrounding vegetation, in no case did the plants grow on land of more than low to medium fertility. Except in the instances noted, they were cut within a few inches of the ground. They were then brought to the laboratory, cut into small pieces with scissors, dried with the aid of an electric fan, ground, and stored in half-gallon jars for analysis. The analytical methods were the usual ones of the Association of Official Agricultural Chemists employed in feed control work. Pentosans were determined by the phloroglucide method.

The time and stage of sampling and the results of the analyses are shown in Tables 1 and 2. Table 3 shows the composition of the leaves (with petioles) only, and Table 4 gives the results of the earlier investigations, to which reference has already been made. Table 5 shows the average composition of certain forage plants as calculated from the average composition tables of Henry and Morrison.

TABLE 2.—*Composition of Ambrosia trifida at various growth stages on moisture-free basis.*

Date collected	Crude protein %	Crude fiber %	N-free extract %	Ether extract %	Ash %	Pentosans %
			1927 Samples			
June 6. .	13.78	20.4	50.0	1.88	13.90	11.30
July 6. .	13.39	29.4	45.3	1.63	10.23	13.97
Aug. 15.	10.82	33.4	47.2	1.89	6.73	14.94
Sept. 15	6.74	43.7	39.9	2.59	7.02	17.36
Oct. 17.	2.95	58.0	33.4	0.67	5.01	20.35
			1928 Samples			
June 7. .	19.95	16.6	47.2	2.88	13.33	10.24
July 7. . .	14.57	22.6	44.6	2.42	15.80	12.99
Aug. 7. .	11.40	37.9	38.4	1.55	10.70	15.79
Sept. 7. .	10.03	40.2	39.6	2.26	7.91	17.30
Oct. 8. . .	8.43	41.2	38.0	5.04	7.34	17.65
			1929 Samples			
June 10.	24.19	14.5	45.3	1.81	14.20	1st cutting
July 10. .	16.23	25.4	42.7	1.90	13.74	2d cutting
July 10. .	17.23	21.6	46.3	2.06	12.78	1st cutting, tops only

TABLE 3.—*Composition of miscellaneous samples of Ambrosia trifida on moisture-free basis.*

Date collected	Description	Crude protein %	Crude fiber %	N-free extract %	Ether extract %	Ash %	Pentosans %
July 6, 1927..	Leaves only	25.52	11.5	44.2	3.67	15.13	8.33
July 7, 1928..	Leaves only	23.57	11.4	46.7	3.42	14.88	7.88
June 10, 1929	Leaves only	28.65	11.1	47.7	1.92	10.62	—
Aug. 7, 1928..	Single large plant	12.12	33.8	41.8	2.04	10.26	15.29

TABLE 4.—*Analyses of Ambrosia trifida previously reported on moisture-free basis.*

Station reporting	Date collected	Crude protein %	Crude fiber %	N-free extract %	Ether extract %	Ash %
Mississippi	June, 1895	8.52	16.49	57.13	2.38	15.48
Kentucky*	Aug. 7, 1895	20.24	18.80	41.06	1.87	18.03
Kentucky†	July 2, 1902	19.78	17.16	45.14	2.20	15.72

*Small growth 2 to 3 feet high having recently been cut.
†Twelve plants averaging 3½ feet tall and ¼ to ½ inch in diameter at base.

TABLE 5.—*Analyses of well-known forage plants at stages indicated on moisture-free basis.**

Forage plant	Stage harvested	Crude protein %	Crude fiber %	N-free extract %	Fat %	Ash %
Alfalfa........	Before bloom	23.4	21.9	39.6	4.5	10.7
Alfalfa........	In bloom	16.2	32.6	38.4	1.9	10.8
Alfalfa leaves..	———	24.1	13.6	44.1	3.6	14.6
Red clover.....	Before bloom	20.9	20.4	46.6	4.0	8.0
Red clover.....	In bloom	15.2	26.8	45.5	4.0	8.6
Soybean......	In bloom	18.7	27.9	39.4	2.9	11.1
Kentucky bluegrass........	Before heading	22.2	21.8	39.0	5.5	11.3
Kentucky bluegrass.......	Headed out	13.5	29.9	42.8	3.6	10.2
Timothy......	Before bloom	10.5	30.3	48.6	3.5	7.1
Timothy......	Early bloom	7.2	33.8	50.8	3.0	5.3

*Calculated from "Average percentage composition of American feeding stuffs" —tables of Henry and Morrison (1).

DISCUSSION

A comparison of the data in Tables 2 and 5 indicates the relative worth of *A. trifida* from the standpoint of composition. Throughout the early growth stages well up toward the time of bloom the crude

protein, nitrogen-free extract, and ash content of the plant run high and the fiber correspondingly low. In these constituents it approaches the composition of the legumes and Kentucky bluegrass. This seems all the more unusual when one considers the rapid rate of growth of *A. trifida* and large yield of dry matter produced by the plant. One might suppose that the rank growth would result in a relatively low protein and high fiber content, but such does not seem to be the case. After the stage of full bloom is past the plants soon become hardened and woody, and no doubt palatability declines in proportionate degree. The ether extract runs about parallel with other common forage plants, while the pentosan content perhaps is somewhat lower. The fiber may reach a rather extreme degree in the matured stalks as shown by the value of this constituent in the sample collected on October 17, 1927.

Turning now to a consideration of the leaves, as shown in Table 3, one finds at least a partial explanation of the high nitrogen character of *A. trifida*. Crude protein is seen to comprise one-fourth of the total dry matter of this portion of the plant at the stages indicated. The protein values equal or exceed those given for alfalfa leaves and in themselves are rather surprising. The ash content of the leaves also runs reasonably high. The fact that the plant is decidedly leafy during its early growth and that a second cutting is possible indicates that it might be made to yield considerable amounts of forage of higher nutritive value than many of our common grasses. Its ability to grow under adverse conditions and its adaptation to bottom and over-flow lands are matters of common observation.

SUMMARY

A study of the chemical composition of *Ambrosia trifida* confirms the earlier reports as to its nitrogenous character and suggests the possibility of its utilization for forage or green manure. Other constituents, including ash, crude fiber, nitrogen-free extract, ether extract, and pentosans, are reported.

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EXPERIENCES WITH THE NEUBAUER METHOD FOR DETERMINING MINERAL NUTRIENT DEFICIENCIES IN SOILS[1]

S. F. THORNTON[2]

Since the beginning of agricultural chemistry one of the chief problems has been the determination of the fertilizer needs of the soil. At first ordinary chemical analysis was used. Later attempts were made to imitate the solvent action of plant roots through the action of dilute solvents (5).[3] The present use of such procedures is illustrated by the work of Lemmermann and Fresenius (11) with 1% citric acid, Fraps (6) and others with 0.2 N nitric acid, and by the chemical field tests of Spurway (20), Bray (3), and Truog. (21).

At present the trend is definitely toward biological procedures, among which may be mentioned the Azotobacter method (17, 18), the Hoffer stalk test (10), the Mitscherlich method (12), and the Neubauer method (13, 14, 15).

Through the action of a large number of rye seedlings growing on a small amount of soil, the Neubauer method makes possible the simultaneous extraction of both available phosphorus and potassium. Since the vegetation test is the foundation of the method and the part to which most of the criticism has been due, the more important factors which might be expected to influence nutrient absorption will be discussed briefly.

Although rye has been generally used and is strongly recommended by Neubauer and Schneider (13), considerable study has been carried out with other plants. Absorption powers of different plants vary widely and, as a rule, other plants have proved less satisfactory than rye. Even with rye, germination, growth, and nutrient absorption vary with the variety, origin, size, etc., of the seed. The importance of this has been emphasized frequently by Neubauer, who has provided a standard seed, so that different workers might obtain comparable results. It is important that the seed be stored in a dry, well-aerated place and that uniform 100-grain lots be selected. Disinfection of the seed is essential as an aid in preventing mold growth

[1]Contribution from the State Chemist's Department, Purdue University Agricultural Experiment Station, Lafayette, Indiana, under a fellowship supported by N. V. Potash Export, My. Abstract of a thesis submitted to the faculty of Purdue University in partial fulfillment of the requirements for the degree of master of science. Presented as part of a symposium on "Diagnosing Soil Deficiencies and Crop Needs" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

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[3]Reference by number is to "Literature Cited," p. 207.

during the vegetation period. A 0.25% "Uspulun" solution has been found satisfactory for this purpose.

A moisture content of 80 grams for all soils is recommended by Neubauer and Schneider (13). This has been found to be approximately the limit of the absorption capacity of the sand. Evidence as to the influence of variations in the water supply is quite conflicting, but indicates that, within reasonable limits, it is not especially great and probably varies with the type of soil being studied. Daily replacement of water losses will permit only very slight variations which certainly are without significance. Our experience has been that peaty soils usually require an additional supply of water, while the sand checks do best with somewhat less than the 80 grams recommended.

Before the publication of the method, Neubauer and Schneider (13) had found that seedlings growing in the dark absorbed the same amounts of nutrients as those growing in the light. Hahne (8) found the influence of light to be very small. These observations have been verified by Gunther (7) and others. They are in complete accord with our experiences in which no differences could be observed for seedlings growing simultaneously in different light intensities or for plants growing at different seasons of the year or under different weather conditions. While the influence of light intensity on nutrient absorption is negligible, a strong, diffused light, distributed as evenly as possible from all directions, is conducive to growth conditions which make the plants more easily handled. In direct sunlight it has been found impossible to obtain proper temperature control.

Maintenance of a temperature very close to 20°C is absolutely essential. It appears that failure in this respect has contributed more to the failure of the method than all other factors combined. Lower temperature retards development of the seedlings, while higher temperatures materially shorten the duration of the growth period. In either case the nutrient absorption and retention is hindered. There seems to be complete agreement upon the importance of temperature control. For instance, Hahne (8) found a difference of 30 to 40% for potassium and over 50% for phosphorus with plants grown at 9° to 12°C and 22° to 23°C. In the present work an attempt to use a temperature of 25°C had to be abandoned. Maximum variations of 2°C are advised. Having blank tests with each series of soil tests tends to compensate to some extent for variations in temperature and other growth conditions, but such compensation is by no means complete.

Dirks (4) adjusted the pH values of soils from 2.9 to 9.0 by treating with acid or lime as required. Between pH 6.0 and 8.3 no significant changes in absorption were found. With decrease of either acidity or

alkalinity outside of these limits, slight increases for absorption of both phosphorus and potassium occurred. Gunther (7) found that, except in very extreme cases, variations in soil reactions had no effect upon nutrient assimilation. Important decreases in nutrient absorption are produced only by extreme cases of acidity and alkalinity such as are seldom met with in agricultural practice.

In the early stages of the development of the method Neubauer and Schneider (13) found that additions of nitrogen had no effect on the absorption of phosphorus and potash. Other workers have found differences due to nitrogen additions, but usually fertilizer additions have had little influence.

Working with 13 different phosphates, covering a very wide range of availability, the author found that potash absorption was not affected by any phosphorus concentration used, but that absorption of phosphorus was increased slightly by additions of potash. Both sand and soil were used in these tests.

The Neubauer method has received its most intensive application in European countries, especially Germany. The German literature, especially that regarding the practical value of the method, is so extensive that its review is not possible here. Suffice it to say, that nearly 200 articles have come to the author's attention during the past few years. There is much criticism of the accuracy of the method but even more commendation of its practical value.

For American soils very little data are available. It is especially unfortunate that much of the limited work undertaken appears to have been concerned more with attempts to effect modifications than to test the procedure seriously.

Such a work is that of Ames and Gerdel (1, 2), a review of which fails to show any study of the true Neubauer method. The only attempt to follow this procedure is reported as having been unsuccessful because of failure to treat the seed properly before planting. The remainder of the work deals with modifications which are of such a nature that they destroy the principles upon which the Neubauer method is founded. For this reason it seems difficult to justify the conclusion that the investigation of the seedling plant method of determining the available soil nutrients indicates that the method devised by Neubauer is not generally applicable.

Salter and Ames (19) reported further upon this work in 1928, but did not give the details of the procedure used. If the modifications used by Ames and Gerdel were continued there would be the same objections to representing their data as results of the Neubauer method. No advantages over purely chemical methods were found for potassium and negative results were always obtained for phosphorus.

Haley and Holben (9), using a modification of the Neubauer method, present data which show a close correlation between the quantities of potassium absorbed by the tops of buckwheat plants and the results of 0.2 N hydrochloric acid extraction.

Wheeting (22) found Neubauer tests and also modifications to include fertilization to be good indicators of the potassium needs of soils.

EXPERIMENTAL METHODS

The soil samples were obtained from the Purdue University Agricultural Experiment Station farms. The directions as given by Neubauer were followed closely. Minnesota seed germinators with glass doors (Fig. 1) were used as growth chambers for the seedlings, making

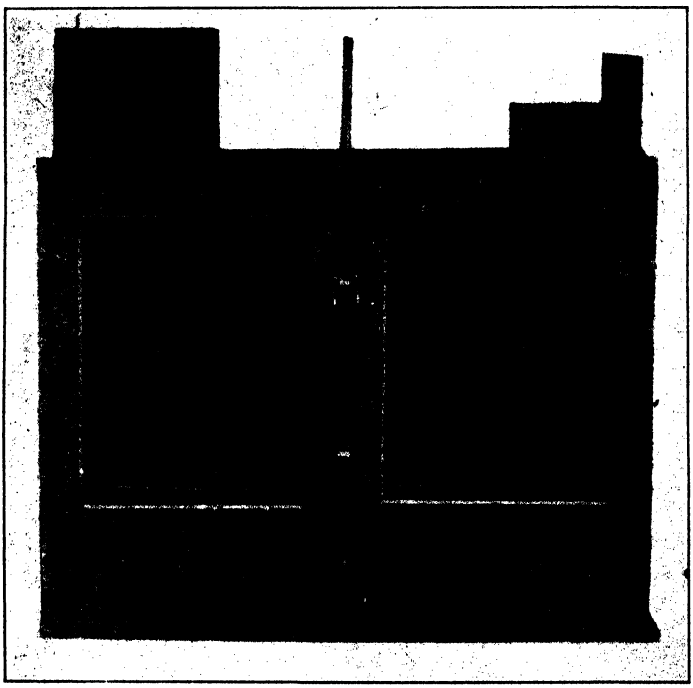

FIG. 1.—Growth chamber for rye seedlings.

possible a temperature control within 1°C. By careful selection of the larger rye seed, a 100-grain weight of 3.5 grams and a germination of above 90% were obtained (Fig. 2). To prevent undue mold growth, all materials, with the exception of the soil itself, were sterilized. The plants were removed from the dishes, freed from sand and soil by careful washing on a sieve in a moderate stream of tap water, dried,

ashed at a temperature of 500° to 550°C, and the ash analyzed for phosphoric acid and potash in the usual manner.

The growth chambers accomodate 36 dishes. With each series of soil samples two blanks, grown on sand alone, were included. Water addition on alternate days was found sufficient.

DISCUSSION OF RESULTS

Limit values for deficiencies are necessarily different for different crops and may be established only after consideration of a large number of results. For the laboratory methods used, the following values are suggested for profitable responses with average crops under Indiana farming conditions:

Illinois phosphate test—"doubtful"
Hoffer stalk test—between "2" and "3"
0.2N HNO_3 extraction—0.005% P_2O_5 and 0.01% K_2O
Neubauer method—4 mgms P_2O_5 and 10 mgms K_2O

FIG. 2.—Ten-day-old rye seedlings showing soil test at left and check at right.

Under European condition, Neubauer established for his method average limit values of 8 mgms P_2O_5 and 24 mgms K_2O, showing that the European level of fertility is much higher than can be profitably maintained here, except for our more intensive crops. An example of this is tobacco which has given profitable responses to potash fertilization when the available potash content of the soil was in excess of 20 mgms.

TABLE 1.—*Bedford fertility series, 1929.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§		Neubauer		Pot tests, grams dry weight			Yield of corn in bushels per acre, 1917–28‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	NPK	NK	NP	
1	L	6.60	L	1	0.0009	0.0148	1.60	9.60	—	—	—	24.3
2	LP	6.10	L	1	0.0006	0.0096	2.00	4.80	103	32	78	41.7
3	LPK	6.20	L	1	0.0003	0.0093	1.60	9.60	97	37	79	44.9
4	LNPK	6.80	L	1	0.0004	0.0089	1.60	8.40	100	30	66	44.2
5	L	6.20	L	1	0.0006	0.0101	0.20	7.80	106	20	74	26.3
6	LNPK+R	6.60	L	1	0.0014	0.0120	1.00	7.90	104	25	70	47.1
7	LPK+R	6.60	L	1	0.0009	0.0134	2.50	8.40	83	30	65	47.5
8	LP+R	6.40	L	1	0.0008	0.0121	2.40	9.00	116	29	82	45.9
9	L	6.40	L	1.5	0.0008	0.0111	1.00	8.40	—	—	—	28.0
10	L+R	6.40	L	1.5	0.0011	0.0126	1.00	5.40	90	13	63	28.6
11	R	5.40	L	1	0.0011	0.0144	1.00	7.80	102	20	94	24.7
12	NPK	5.70	L	1	0.0006	0.0138	1.80	6.60	—	—	—	39.6
13	L	6.10	L	1	0.0004	0.0132	0.40	7.20	—	—	—	24.2
14	O	5.40	L	0	0.0004	0.0123	0.00	7.20	89	4	77	20.6
15	M	5.40	L	0	0.0008	0.0147	2.40	9.60	—	—	—	37.4
16	LM	6.70	L	1	0.0009	0.0153	1.00	6.60	—	—	—	42.3
17	L	6.70	L	1	0.0008	0.0129	1.60	9.60	—	—	—	26.1
18	LMP	6.20	D	0	0.0004	0.0147	1.00	8.40	—	—	—	52.6
19	LMPK	6.40	D	1	0.0004	0.0121	2.00	7.90	—	—	—	52.7
20	LMNPK	6.20	D	0	0.0009	0.0121	0.60	7.90	—	—	—	50.8
21	L	6.40	L	0	0.0016	0.0129	1.20	7.60	—	—	—	24.5

*L = lime; P = phosphorus; K = potassium; N = nitrogen; M = manure; R = residue; O = untreated.
†L = low; D = doubtful.
‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.
§Analytical work by R. A. Weaver.
‖From the records of the Agronomy Department.

The Bedford fertility series, shown in Table 1, is a Bedford silt loam, very deficient in phosphorus but showing only small responses to potash additions. The phosphorus deficiency is confirmed by all methods used. A sufficient supply of potash is shown by the Hoffer stalk test in all cases and by the 0.2 N nitric acid.

For no plat is the potash value up to the 10 mgms established for the Neubauer method. In spite of the fact that in no case is the value very low, there is a definite indication of a moderate potash deficiency. This is confirmed by the results of pot tests, which show a distinct response to potash applications when the phosphorus level is raised. Average yield data show slight responses to potash fertilization, except on the manured plats. Such responses undoubtedly would be much greater if the extremely low phosphorus level were removed as a limiting factor. All biological field tests necessarily show the relative supply of a nutrient as compared to other possible limiting factors rather than the actual amount present.

Table 2 gives the results for the Culver fertility series, a sandy soil which has proved deficient in both phosphorus and potassium, with

TABLE 2.—*Culver fertility series, 1928.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§		Neubauer		Yield of corn in bushels per acre, 1924–28‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	
1	L..........	6.10	H	—	0.0178	0.0071	0.70	0.00	27.9
2	LMNPK...	6.10	H	—	0.0161	0.0077	2.80	1.80	36.6
3	LMPK.....	5.80	H	—	0.0161	0.0078	2.50	3.00	36.7
4	LMP.......	5.80	H	—	0.0157	0.0087	3.90	2.40	37.4
5	L..........	5.80	H	—	0.0132	0.0067	0.30	1.20	32.6
6	LM+1 ton RP......	6.00	H	—	0.0290	0.0070	1.70	0.00	40.3
7	LM+½ ton SP.......	6.00	H	—	0.0156	0.0074	1.90	0.00	38.5
8	LM........	5.90	H	—	0.0111	0.0062	1.50	1.80	36.6
9	L..........	6.00	H	—	0.0110	0.0075	0.00	0.60	27.3
10	O..........	5.50	H	—	0.0108	0.0077	0.00	0.00	23.9
11	NPK.......	5.30	H	—	0.0154	0.0081	2.30	1.80	29.0
12	LNPK.....	6.20	H	—	0.0148	0.0066	2.00	1.80	36.0
13	L..........	6.00	H	—	0.0141	0.0087	0.70	0.60	32.2
14	LPK.......	5.90	H	—	0.0129	0.0099	2.90	1.80	33.6
15	LP.........	5.90	H	—	0.0138	0.0085	1.70	0.00	30.7
16	LNPK.....	5.80	H	—	0.0111	0.0081	2.00	2.40	34.9
17	L..........	5.90	H	—	0.0130	0.0070	1.00	1.70	28.7
18	LNPK.....	5.90	H	—	0.0113	0.0077	2.40	3.70	33.0
19	LNPK.....	5.90	H	—	0.0097	0.0097	3.00	4.30	31.4
20	L..........	5.70	H	—	0.0087	0.0115	1.10	0.00	27.8
21	M.........	5.30	H	—	0.0097	0.0124	2.20	4.90	33.8

*L=lime; M=manure; N=nitrogen; P=phosphorus; K=potassium; RP=rock phosphate; SP=superphosphate; O=untreated.
†H=high.
‡Frosted before maturity and no stalk tests made.
§Analytical work by R. A. Weaver.
‖From the records of the Agronomy Department.

nitrogen and possibly water supply as even more limiting factors. Both the 0.2 N nitric acid extraction and the Illinois phosphate test show high phosphorus values for all plats, while according to the Neubauer method there is always a distinct deficiency.

For potash a deficiency is shown for all plats by the Neubauer method and by the 0.2 N nitric acid extraction for all except Nos. 20 and 21. Field responses appear to be limited by nitrogen and water supply. With plats 6 and 7 applications of phosphorus, in addition to manure, have produced quite noticeable responses. The unusually high phosphorus values for this soil, and especially the extremely high values for plat 6 where rock phosphate has been applied, given by both the 0.2 N nitric acid extraction and the Illinois phosphate test, are worthy of further consideration.

The Jennings County fertility series, shown in Table 3, is a Clermont silt loam which has proved very deficient in both phosphorus and potash. The Neubauer method shows severe phosphorus and potash deficiencies for all plats. According to the Hoffer stalk test,

TABLE 3.—*Jennings County fertility series, 1928.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§ % P_2O_5	0.2 N HNO_3§ % K_2O	Neubauer Mgs P_2O_5	Neubauer Mgs K_2O	Yield of corn in bushels per acre, 1921–28‖
1	O	5.40	L	1.5	0.0009	0.0060	1.60	0.90	24.7
2	L	5.60	L	2	0.0017	0.0088	1.60	4.00	40.2
3	L+R	5.60	L	1.5	0.0012	0.0092	2.00	4.60	43.8
4	LP+R	5.70	D	2	0.0014	0.0078	2.20	2.80	53.5
5	LPK+R	5.60	D	1	0.0016	0.0081	0.60	4.60	58.5
6	L	5.60	L	3	0.0017	0.0077	1.80	4.50	43.1
7	LNPK+R	5.60	L	1.5	0.0011	0.0089	0.80	5.00	61.4
16	O	5.40	L	2.5	0.0008	0.0058	0.80	0.00	32.7
17	NPK	5.40	L	1.5	0.0017	0.0090	1.00	5.00	46.7
18	L	6.20	L	3	0.0009	0.0079	0.80	3.20	46.3
19	LP	6.40	L	3	0.0012	0.0075	1.10	3.50	55.7
20	LPK	6.20	L	1.5	0.0014	0.0082	0.80	4.70	61.0
21	LNPK	6.10	L	2	0.0009	0.0079	0.90	4.40	60.8
30	L	6.10	L	1	0.0008	0.0055	1.30	2.00	42.3
31	LMN+1 ton RP	6.10	H	1	0.0110	0.0057	1.60	0.50	62.0
32	LMNK+½ ton SP	6.20	M	—	0.0016	0.0070	1.60	1.00	69.9
33	MNK+1 ton RP	5.40	H	—	0.0059	0.0089	1.00	3.00	61.4
34	L	6.20	L	—	0.0012	0.0071	1.20	2.70	42.4
35	O	5.30	L	—	0.0011	0.0068	1.10	2.30	29.5

*O = untreated; L = lime; R = residue; P = phosphorus; K = potassium; N = nitrogen; M = manure; RP = rock phosphate; SP = superphosphate.
†L = low; D = doubtful; M = medium; H = high.
‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.
§Analytical work by R. A. Weaver.
‖From the records of the Agronomy Department.

there is a moderate potash deficiency on plats 6, 18, and 19 only. The 0.2 N nitric acid extraction shows a moderate potash deficiency for all plats and for phosphorus a severe deficiency with the exception of plats 31 and 33, where rock phosphate has been applied. With the exception of plat 32, results of the Illinois phosphate test are similar.

Table 4 shows a Newton fine sandy loam from the Pinney-Purdue farm near Wanatah. Results of 0.2 N nitric acid extraction show a high value for potash in nearly all cases, while results of the Neubauer method are always low. Again the high phosphorus values with plats receiving rock phosphate applications are evident.

TABLE 4.—*Pinney-Purdue fertility series, 1928.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§		Neubauer		Yield of corn in bushels per acre 1920–28‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	
1	O	5.00	L	3	0.0023	0.0206	1.00	4.30	7.9
2	L	5.50	L	3	0.0019	0.0131	0.50	2.40	17.2
3	LPK+CS	5.70	L	1	0.0039	0.0180	1.80	4.30	26.8
4	LNPK	5.70	L	1	0.0038	0.0146	1.60	5.50	24.9
5	LPK	5.70	L	1	0.0036	0.0141	1.80	3.10	26.2
6	L	5.60	L	4	0.0028	0.0133	1.00	1.80	17.4
7	LK+RP	5.70	M	3	0.0097	0.0144	1.80	4.90	24.0
8	LK	5.60	L	1	0.0038	0.0106	1.00	1.20	23.7
9	LP	5.70	L	4	0.0043	0.0105	2.00	1.80	19.9
10	L	5.70	L	3	0.0035	0.0081	1.10	1.20	18.3
11	O	4.90	L	–	0.0038	0.0116	1.80	1.20	8.2
12	M	4.90	L	–	0.0038	0.0142	1.80	3.70	14.0
13	LM	5.60	L	–	0.0044	0.0114	2.00	1.20	27.9
14	L	5.50	L	–	0.0038	0.0116	2.00	3.70	19.0
15	LM+RP	5.50	L	3	0.0234	0.0118	1.60	4.90	30.0
16	LMP	5.40	L	1	0.0051	0.0107	1.40	1.20	28.2
17	LMPK	5.40	L	–	0.0051	0.0128	1.20	0.00	29.1
18	L	5.30	L	–	0.0036	0.0100	1.10	0.00	17.2
19	LK+½ ton SP	5.50	D	–	0.0118	0.0079	2.80	4.90	30.2
20	LK+1 ton RP	5.60	D	–	0.0264	0.0080	1.00	0.00	26.8
21	LK+1 ton RP+G	5.70	D	–	0.0287	0.0105	1.80	6.70	28.9
22	L	5.50	L	–	0.0065	0.0089	1.80	3.10	21.9
23	LK+G	5.50	L	–	0.0041	0.0153	1.00	3.70	22.9
24	LK+Tr. SP+G	4.70	L	–	0.0047	0.0128	2.00	3.40	27.4
25	LK+Tr. SP	5.50	L	–	0.0100	0.0116	3.20	4.90	27.1
26	O	5.50	L	–	0.0086	0.0154	1.70	7.30	6.7
27	L	5.50	L	–	0.0046	0.0126	1.20	5.50	13.9

*O = untreated; L = lime; P = phosphorus; K = potassium; CS = calcuim silicate; N = nitrogen; RP = rock phosphate; M = manure; SP = superphosphate; G = gypsum; Tr. SP = triple superphosphate.

†L = low; D = doubtful; M = medium.

‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.

§Analytical work by R. A. Weaver.

‖From the records of the Agronomy Department.

nitrogen and possibly water supply as even more limiting factors. Both the 0.2 N nitric acid extraction and the Illinois phosphate test show high phosphorus values for all plats, while according to the Neubauer method there is always a distinct deficiency.

For potash a deficiency is shown for all plats by the Neubauer method and by the 0.2 N nitric acid extraction for all except Nos. 20 and 21. Field responses appear to be limited by nitrogen and water supply. With plats 6 and 7 applications of phosphorus, in addition to manure, have produced quite noticeable responses. The unusually high phosphorus values for this soil, and especially the extremely high values for plat 6 where rock phosphate has been applied, given by both the 0.2 N nitric acid extraction and the Illinois phosphate test, are worthy of further consideration.

The Jennings County fertility series, shown in Table 3, is a Clermont silt loam which has proved very deficient in both phosphorus and potash. The Neubauer method shows severe phosphorus and potash deficiencies for all plats. According to the Hoffer stalk test,

TABLE 3.—*Jennings County fertility series, 1928.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§		Neubauer		Yield of corn in bushels per acre, 1921–28‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	
1	O	5.40	L	1.5	0.0009	0.0060	1.60	0.90	24.7
2	L	5.60	L	2	0.0017	0.0088	1.60	4.00	40.2
3	L+R	5.60	L	1.5	0.0012	0.0092	2.00	4.60	43.8
4	LP+R	5.70	D	2	0.0014	0.0078	2.20	2.80	53.5
5	LPK+R	5.60	D	1	0.0016	0.0081	0.60	4.60	58.5
6	L	5.60	L	3	0.0017	0.0077	1.80	4.50	43.1
7	LNPK+R	5.60	L	1.5	0.0011	0.0089	0.80	5.00	61.4
16	O	5.40	L	2.5	0.0008	0.0058	0.80	0.00	32.7
17	NPK	5.40	L	1.5	0.0017	0.0090	1.00	5.00	46.7
18	L	6.20	L	3	0.0009	0.0079	0.80	3.20	46.3
19	LP	6.40	L	3	0.0012	0.0075	1.10	3.50	55.7
20	LPK	6.20	L	1.5	0.0014	0.0082	0.80	4.70	61.0
21	LNPK	6.10	L	2	0.0009	0.0079	0.90	4.40	60.8
30	L	6.10	L	1	0.0008	0.0055	1.30	2.00	42.3
31	LMN+1 ton RP	6.10	H	1	0.0110	0.0057	1.60	0.50	62.0
32	LMNK+½ ton SP	6.20	M	—	0.0016	0.0070	1.60	1.00	69.9
33	MNK+1 ton RP	5.40	H	—	0.0059	0.0089	1.00	3.00	61.4
34	L	6.20	L	—	0.0012	0.0071	1.20	2.70	42.4
35	O	5.30	L	—	0.0011	0.0068	1.10	2.30	29.5

*O = untreated; L = lime; R = residue; P = phosphorus; K = potassium; N = nitrogen; M = manure; RP = rock phosphate; SP = superphosphate.

†L = low; D = doubtful; M = medium; H = high.

‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.

§Analytical work by R. A. Weaver.

‖From the records of the Agronomy Department.

there is a moderate potash deficiency on plats 6, 18, and 19 only. The 0.2 N nitric acid extraction shows a moderate potash deficiency for all plats and for phosphorus a severe deficiency with the exception of plats 31 and 33, where rock phosphate has been applied. With the exception of plat 32, results of the Illinois phosphate test are similar.

Table 4 shows a Newton fine sandy loam from the Pinney-Purdue farm near Wanatah. Results of 0.2 N nitric acid extraction show a high value for potash in nearly all cases, while results of the Neubauer method are always low. Again the high phosphorus values with plats receiving rock phosphate applications are evident.

TABLE 4.—*Pinney-Purdue fertility series, 1928.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§		Neubauer		Yield of corn in bushels per acre 1920–28‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	
1	O	5.00	L	3	0.0023	0.0206	1.00	4.30	7.9
2	L	5.50	L	3	0.0019	0.0131	0.50	2.40	17.2
3	LPK+CS	5.70	L	1	0.0039	0.0180	1.80	4.30	26.8
4	LNPK	5.70	L	1	0.0038	0.0146	1.60	5.50	24.9
5	LPK	5.70	L	1	0.0036	0.0141	1.80	3.10	26.2
6	L	5.60	L	4	0.0028	0.0133	1.00	1.80	17.4
7	LK+RP	5.70	M	3	0.0097	0.0144	1.80	4.90	24.0
8	LK	5.60	L	1	0.0038	0.0106	1.00	1.20	23.7
9	LP	5.70	L	4	0.0043	0.0105	2.00	1.80	19.9
10	L	5.70	L	3	0.0035	0.0081	1.10	1.20	18.3
11	O	4.90	L	–	0.0038	0.0116	1.80	1.20	8.2
12	M	4.90	L	–	0.0038	0.0142	1.80	3.70	14.0
13	LM	5.60	L	–	0.0044	0.0114	2.00	1.20	27.9
14	L	5.50	L	–	0.0038	0.0116	2.00	3.70	19.0
15	LM+RP	5.50	L	3	0.0234	0.0118	1.60	4.90	30.0
16	LMP	5.40	L	1	0.0051	0.0107	1.40	1.20	28.2
17	LMPK	5.40	L	–	0.0051	0.0128	1.20	0.00	29.1
18	L	5.30	L	–	0.0036	0.0100	1.10	0.00	17.2
19	LK+½ ton SP	5.50	D	–	0.0118	0.0079	2.80	4.90	30.2
20	LK+1 ton RP	5.60	D	–	0.0264	0.0080	1.00	0.00	26.8
21	LK+1 ton RP+G	5.70	D	–	0.0287	0.0105	1.80	6.70	28.9
22	L	5.50	L	–	0.0065	0.0089	1.80	3.10	21.9
23	LK+G	5.50	L	–	0.0041	0.0153	1.00	3.70	22.9
24	LK+Tr. SP +G	4.70	L	–	0.0047	0.0128	2.00	3.40	27.4
25	LK+Tr. SP	5.50	L	–	0.0100	0.0116	3.20	4.90	27.1
26	O	5.50	L	–	0.0086	0.0154	1.70	7.30	6.7
27	L	5.50	L	–	0.0046	0.0126	1.20	5.50	13.9

*O = untreated; L = lime; P = phosphorus; K = potassium; CS = calcuim silicate; N = nitrogen; RP = rock phosphate; M = manure; SP = superphosphate; G = gypsum; Tr. SP = triple superphosphate.

†L = low; D = doubtful; M = medium.

‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.

§Analytical work by R. A. Weaver.

‖From the records of the Agronomy Department.

The Vincennes fertility series shown in Table 5 represents a Vigo loam which has shown very good responses to both phosphorus and potash applications. Correspondingly low values are obtained with both the 0.2 N nitric acid extraction and the Neubauer method. For a majority of the plats the stalk test shows no potash deficiency. However, the hybrid corn used as a test plant for this series has since been found to show notably low iron accumulations in comparison to other strains. The Illinois phosphate test shows no phosphorus deficiencies in the majority of cases.

The Wilson farm fertility series, shown in Table 6, is from the soils and crops farm near Lafayette. The soil is a Miami or Crosby silt loam in the high places and a Clyde or Brookston silt loam in the depressions. It is a fairly fertile soil on which fertilizer responses have been less than with the other soils being considered. The sub-soil is relatively high in available potash and very low in available phosphorus.

TABLE 5.—*Vincennes fertility field, 1929.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO_3§ % P_2O_5	0.2 N HNO_3§ % K_2O	Neubauer Mgs P_2O_5	Neubauer Mgs K_2O	Yield of corn in bushels per acre, 1925–29‖
1	L	6.30	H	3	0.0063	0.0070	2.40	4.60	34.1
2	LP	6.00	M	3	0.0039	0.0064	2.50	2.80	38.8
3	LPK	5.80	H	3	0.0043	0.0067	1.80	5.20	48.0
4	L	6.00	H	3	0.0068	0.0115	2.60	5.20	41.1
5	LNPK	6.00	D	3	0.0017	0.0059	2.00	4.60	48.9
6	NPK	5.40	L	2	0.0016	0.0055	2.00	4.00	46.9
7	L	5.60	L	3	0.0019	0.0069	2.00	4.00	35.3
8	O	5.40	L	2	0.0016	0.0072	1.60	2.20	35.4
9	M	5.20	L	2	0.0016	0.0071	2.20	2.20	56.6
10	L	5.50	D	1	0.0024	0.0071	1.40	2.00	40.6
11	LM	6.20	D	1	0.0019	0.0068	1.80	2.80	56.3
12	LMP	5.50	M	1	0.0028	0.0062	1.80	2.50	61.0
13	L	5.30	D	2	0.0019	0.0067	1.40	2.30	38.3
14	LMPK	5.80	M	1	0.0022	0.0065	1.60	3.50	64.6
15	LMNPK	6.20	M	2	0.0028	0.0079	1.80	3.20	64.1
16	L	6.20	M	3	0.0022	0.0065	2.80	4.10	36.9

*L = lime; P = phosphorus; K = potassium; N = nitrogen; O = untreated; M = manure.

†L = low; D = doubtful; M = medium; H = high.

‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.

§Analytical work by R. A. Weaver.

‖From the records of the Agronomy Department.

This series shows, primarily, a comparison between different phosphates, especially rock phosphate and superphosphate. In comparison to superphosphate, rock phosphate applications give much higher values with both the 0.2 N nitric acid extraction and the Illinois phosphate test, while with the Neubauer method superphosphate usually

TABLE 6.—*Wilson Farm fertility series, 1929.*

Plat No.	Treatment*	pH	Illinois phosphate test†	Stalk test‡	0.2 N HNO₃§		Neubauer		Pot tests, grams dry weight			Yield of corn in bushels per acre, 1915–29‖
					% P_2O_5	% K_2O	Mgs P_2O_5	Mgs K_2O	NPK	NK	NP	
601	M	5.10	M	3	0.0180	0.0115	5.00	8.20	—	—	—	59.6
602	M+SP (72 lbs. P_2O_5)	5.20	D	2	0.0145	0.0106	5.80	7.00	—	—	—	63.3
603	M+RP (288 lbs. P_2O_5)	5.70	H	1	0.0339	0.0091	4.40	6.40	—	—	—	62.8
604	M	5.90	M	2	0.0051	0.0094	4.20	8.20	—	—	—	63.3
605	M+SP (48 lbs. P_2O_5)	5.70	D	3	0.0103	0.0083	5.00	7.60	—	—	—	64.2
606	M+RP (193 lbs. P_2O_5)	5.90	H	2	0.0349	0.0099	5.00	6.80	—	—	—	63.7
607	M	5.60	D	2	0.0157	0.0147	5.60	11.20	—	—	—	64.6
608	M+SP (24 lbs. P_2O_5)	5.90	D	2	0.0087	0.0102	5.20	8.80	—	—	—	64.7
609	M+RP (96 lbs. P_2O_5)	5.80	M	3	0.0204	0.0116	5.00	10.00	—	—	—	64.2
610	M	6.20	M	2	0.0062	0.0091	2.80	8.20	—	—	—	62.6
611	M+B (48 lbs. P_2O_5)	6.20	M	2	0.0086	0.0093	3.80	10.60	—	—	—	61.7
612	M+BS (48 lbs. P_2O_5)	6.20	D	3	0.0070	0.0102	3.40	8.20	—	—	—	61.8
613	M	6.00	D	3	0.0070	0.0083	3.40	11.20	—	—	—	59.7
614	SP (48 lbs. P_2O_5)	5.80	M	4	0.0047	0.0104	2.60	5.90	100	90	87	44.7
615	RP (192 lbs. P_2O_5)	5.50	H	4	0.0141	0.0068	2.00	6.80	92	80	75	40.6
616	O	5.80	H	4	0.0047	0.0075	1.60	5.90	94	58	62	38.5
617	12 lbs. N, 50 lbs. K_2O, (48 lbs. P_2O_5) SP	5.80	M	3	0.0063	0.0084	2.80	2.10	92	87	85	52.3
618	12 lbs. N, 50 lbs. K_2O, (192 lbs. P_2O_5) RP	5.80	H	3	0.0118	0.0073	2.60	6.90	97	82	82	52.8
619	M	5.80	D	2	0.0038	0.0107	2.00	8.10	104	99	85	60.8
620	M+2,000 lbs. RP	5.80	H	2	0.0255	0.0084	3.00	5.00	97	89	78	60.1
621	M+1,000 lbs. SP	5.80	M	3	0.0079	0.0086	4.20	3.80	91	83	51	60.5
622	M	6.20	D	2	0.0012	0.0092	2.00	10.60	—	—	—	60.2

*M = manure; SP = superphosphate; RP = rock phosphate; B = bone; BS = basic slag; N = nitrogen; K = potassium.
†D = doubtful; M = medium; H = high.
‡Results by J. F. Trost. Numbers refer to intensity of iron accumulation.
§Analytical work by R. A. Weaver.
‖From the records of the Agronomy Department.

gives somewhat higher values. With the exception of the unmanured plats a fairly high nutrient level is shown by all methods. On the unmanured plats an appreciable deficiency of both phosphorus and potash is found by the Neubauer method and for potash by the 0.2 N nitric acid extraction. Especially interesting is the low potash value with the Neubauer method and pot tests for plats 620 and 621 which have received high phosphate applications. For most plats the stalk test shows about the same moderate potash deficiency that is shown by the Neubauer method.

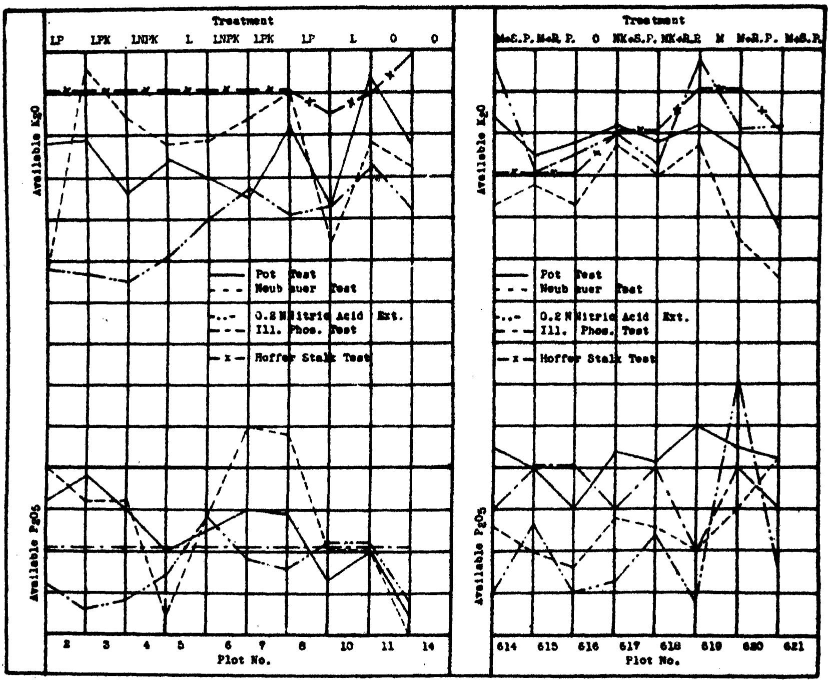

FIG. 3.—*Left*, Bedford Series; *right*, Wilson Farm Series.

Fig. 3 includes those soils for which results of pot tests are available. It shows in a detailed manner comparative results of the different methods. Since only relative values are used the form of the graphs and not their actual positions should be considered.

If we take as a standard the results of the pot tests, there is apparent for both phosphorus and potash a much better correlation with the Neubauer values than with any other method used. As illustrated by plats 620 and 621 of the Wilson Farm series, where large phosphate applications would be expected to effect an increase in the phosphate level rather than a decrease, it seems evident that in some

instances the Neubauer values are more nearly correct than the results of the pot tests. Since the variations within each soil series are quite small, this correlation is even more remarkable. The phosphorus results for the Wilson Farm series emphasize the sensitiveness of both the 0.2 N nitric acid extraction and the Illinois phosphate test to rock phosphate applications.

SUMMARY

A detailed discussion of the Neubauer method for determining nutrient deficiencies in soils is presented.

Using the 0.2 N nitric acid extraction, Neubauer method, Illinois phosphate test, Hoffer stalk test, pot tests, and field yields, comparative results for six soil series are given.

With certain soils, especially where single severe deficiencies exist, all methods give correct indications as to the available nutrient supply of the soil; but in numerous instances the correlation between the different methods is very poor.

Generally, the results of the Neubauer method are found in closest agreement with results of pot tests and with results of field tests when proper consideration is given to other possible limiting factors.

Especially apparent with the 0.2 N nitric acid extraction and the Illinois phosphate tests are the extremely high phosphate results for all soils having received applications of phosphate rock and for soils of the Culver sand series regardless of previous fertilization.

As tentative limit values for deficiencies with the Neubauer method as applied to average field crops under Indiana farming conditions, 4 mgms P_2O_5 and 10 mgms K_2O are suggested.

Of the factors affecting nutrient absorption by the seedlings, light intensity, moisture content, soil reaction, and the presence of other nutrients are of minor importance; but both selection of seed and temperature control require the utmost attention.

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SOME PASTURE IMPROVEMENT PROBLEMS[1]

J. S. OWENS[2]

Pasture research has centered mainly upon a few species of plants and their response to certain cultural treatments, particularly the applications of lime, nitrogen, phosphorus, and potassium. There has been sufficient experimentation to justify re-evaluation of some of the earlier work and to point the way for more valuable investigations.

In the opinion of the writer, the greatest defect of research has been in not securing adequate means of measurement. In reviewing a discussion on methods of pasture research, Noll (7)[3] points out that more evidence is needed concerning the relation of responses on permanent mowings and similar treatments on grazed land, and that pasture production in terms of maintenance and animal products is of most value and "seems to be the ultimate criteria for determining the value of any treatment."

That evaluation of pasture plants harvested as hay or even when cut at more frequent intervals may be an unsatisfactory measurement of production as pasture has been indicated by Dustman and Shriver (4), Shutt, Hamilton, and Selwyn (8), Woodman, Norman, and Bee (11), and Hopper and Nesbitt (6). These writers found wide variations in quantity of growth and chemical composition in the several species studied when harvested at different intervals. When cut frequently, the percentage of protein was approximately twice what it was when cut as hay, but the seasonal production of protein, carbohydrates, and dry matter was not as large. Both close clipping and grazing appeared to change the composition of the vegetation in the experiments conducted by Woodman and associates. Further, the production in droughty seasons was affected by the frequency of the cutting.

Even though it were possible to find a factor which would make it practicable to convert "clippings" into pasture, there would remain the problem of management of the grazing to correspond to the uniform cutting. This problem was ignored by White and Holben (10) when comparing production of pasture grasses (cut as hay) with harvested crops grown in a rotation. The rotation crops could be pre-

[1]Contribution from the Department of Agronomy, Connecticut Agricultural College, Storrs, Conn. Presented as part of a symposium on "An Extension Program for Pasture Improvement" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Extension Agronomist.

[3]Reference by number is to "Literature Cited," p. 214.

served until needed, but what would be the value of the excess pasture if it were not eaten during the period of rapid growth? A change in protein content of *Andropogon virginicus* from 11.16% on June 10 to 5.88% on September 11, when not cut previously, was found by Dustman and Van Landingham (5). Many analyses indicate a similar change in composition with most pasture grasses as they mature and die.

There appear to be many advantages of studying pastures through grazing, yet this has been done in only a few instances. To overcome the variations in soil conditions, the difference in capacity of animals, and the unavoidable irregularities in grazing, experiments must include a large number of animals and several acres of land. To overcome seasonal influences and to determine the accumulative effects of varied treatments upon the flora and soil, treatments and measurements must be continued several years before their greatest usefulness is attained. Grazing experiments are costly in money and effort; a possible explanation for their absence.

Many of the English experiments have included grazing with sheep. It is generally recognized that because sheep graze closer than cattle and distribute their droppings more evenly, the effect upon the turf is not identical. While much of the pasture in the East is used by cows in milk production, the complications necessitated by supplemental feeding, variation in lactation periods, difference in breeds, etc., make the use of dairy cows more complex than the use of other types of animals. White (9) contends that since the measurements from the Storrs grazing experiment are in terms of thermal production, including both gains and maintenance of the steers, conversion into maintenance of dairy cows and milk production is feasible.

Some problems are involved in the management of pastures for dairy animals which do not appear to have been given consideration in any grazing experiments. The early growth may be too high in protein without carbohydrate supplements. Dustman and Shriver (4) found orchard grass containing over 26% protein in the spring. There are many reports of bluegrass and white clover analyzing over 20% protein in the earlier stages of growth. These suggest that a mixed flora containing some of the more carbonaceous plants may be preferable to pure stands of those which are highest in protein.

Dairy farmers are frequently indifferent towards pastures because they have experienced much fluctuation in milk production during the pasture season. The typical Connecticut dairyman has enough pasture to replace all or nearly all of the hay and silage and one-half of the grain from about May 15 to July 1 or July 15. After this time,

the pasture may maintain the young and dry stock, but does little more. The best pastures are ready for grazing the first of May and crops such as alfalfa grow into November. Climatically, then, the pasture season is six months instead of two. Most experiments have been planned to measure quantity and quality of growth instead of the utilization of all of the season available in our humid climate. Top dressing permanent pastures may even accentuate this difference.

In an extensive grazing experiment in this state,[4] an average of the thermal production in percentage of the total up to July 15 for the seasons of 1927, 1928, and 1929 was as follows: No treatment, 50.4%; limestone, superphosphate, and potash, 63.6%; limestone and superphosphate, 67.2%; limestone and complete fertilizer (one-half nitrogen in spring and one-half in July 1929 only) 71.2%; complete fertilizer (all of the nitrogen applied in the spring), 76.4%. Seemingly there is some relation between the percentage of white clover and prolonging the growing period as the plats with the largest percentage of clover furnish the most summer pasture. Those in charge of the Hohenheim demonstration at the Massachusetts Agricultural College have given the writer the impression that the high fertilization, as compared with the unfertilized area, did not reduce the seasonal fluctuation in growth during the dry season of 1929.

On the basis of the foregoing statements, permanent pastures can be relied upon for succulent growth for only half of the entire pasture season. If the growth is more than can be used before midsummer, much of the herbage for the second half of the season will be mature, less palatable, and lower in protein and in total digestible nutrients.

If permanent pastures cannot be made adequate for the entire season, supplementary pastures assume new importance. Zavitz and Squirrell (12) cut a variety of seeded grasses and clovers five times a season over a period of five years. There was a variation of 16% in the portion of the season's production at the first cutting and even greater percentage differences in midsummer. For instance, orchard grass produced only 40% of the total yield at the first cutting and 13% at the last, while mammoth red clover produced 56.2% and 6.3%, respectively. A mixture of oats, sorghum, and hairy vetch gave a more uniform growth than most of the pure seedings.

An investigation of the literature reveals almost nothing which serves to compare the many crops with possibilities as supplementary pasture. How much pasture will orchard grass, tall oat grass, red clover, sweet clover, or alfalfa make as compared with Kentucky bluegrass, white clover, red top, or Rhode Island bent grass? It is even possible that

[4]Unpublished data, Storrs Experiment Station, supplied by B. A. Brown.

the plants in the first group will generally make more economical pasture than those in the second group. Not only is the production value as pasture of such plants as red clover and alfalfa unknown, but little is known of their management as pasture under eastern conditions.

Some possibilities being utilized by Connecticut farmers for supplementary pasture are second and third crops of alfalfa; second crop clover and aftermath on grass land; spring-seeded sweet clover; and barley, rye, and vetch seeded in corn and after potatoes and tobacco. From the somewhat limited experience of our farmers, alfalfa is a promising supplemental crop. By harvesting the first crop and allowing the second and third to approach maturity and by rotating the grazing and not pasturing closely, the stands are seldom injured. The older stands are contaminated with grass, and little loss is involved should the alfalfa be destroyed.

Sweet clover has possibilities as an annual. By seeding in early spring much pasture is secured from July 15 until November. Reseeding the following spring is a simple matter on sandy soils for which sweet clover is particularly well suited.

Land suitable for rotation or temporary pastures may not be available on every farm. In Connecticut, according to the 1925 census, there is 0.9 acre of tillable pasture land for every cow. There are 3 acres in grass hay per cattle unit, or approximately three times as much land as needed for hay when clover and alfalfa are grown. Thus, with good farming, much hay land may be released for pasture. Other New England and middle Atlantic states vary from 0.5 to 1½ acres of tillable pasture per cattle unit. In some sections, grain farming has become less profitable and rotation or temporary pastures might be a good substitute. The grass hay market has disappeared. Since legumes yield more per acre than grass, a change to them also means more good land available for pasture production.

Much of the difficulty in developing programs for improvement of pasture, whether it be for individual farms or for groups, arises from the frequent and extreme variations in soils. Even parts of the same fields in this state are so different that treatments suitable for one portion might be a failure on another. Observations by the writer on test plats on many different soils, over a period of 10 years, have led to the conclusion that this is one of the most important problems. Cooper, Wilson, and Barron (3) have attempted to establish a basis for determining a relation between soil conditions and the dominance of several pasture plants. It would appear impractical ever to measure the pasture production capacity of every soil condition. Therefore, satisfactory application of response to treatments in many condi-

tions will depend upon finding a knowledge of plant requirements and soil conditions such as these workers have suggested.

In Connecticut, pasture improvement is considered an integral part of a larger program for more efficient production of dairy feeds. The value of pasture is not the value of the feed it may replace as other crops are grown, but as the other crops *may* be grown No other conception of pasture seems adequate because the permanence of the dairy industry is dependent upon competitive costs with areas which have some natural advantages in their favor.

The extension program has been in the developing stages for several years and will be altered continuously as new information demands. Brown and Slate (2) have reported the results of an extensive pasture grazing experiment which is now in its tenth year. A typical stony, neglected pasture was cleared of brush and divided into nine 4-acre plats and more recently was subdivided into 16 smaller plats. Various treatments of limestone, nitrogen, phosphorus, and potassium were then topdressed without cultivating or seeding. Marked changes have occurred in the flora and in the quantity and quality of growth. The production, as measured by gains in weight and maintenance of steers, has shown a striking response to phosphorus, consistent and increasing effects from the limestone, doubtful response to potassium, and increases from nitrogen insufficient to repay the cost of the applications.

Beginning in 1919, the extension workers started small pasture improvement tests on permanent pasture by applying lime, nitrogen, phosphorus, and potassium in various combinations on about 75 farms scattered over the state. On soils with a compact substrata, an indication of good moisture retention capacity, responses have appeared similar to those in the grazing test. In fact, on several soils, marked effects from a single application of lime are apparent at the end of the twelfth season.

The measured production at Storrs, and observations on similar treatments throughout the state, have appeared to justify the conclusion that all pasture soils similar to those in the grazing experiment would give satisfactory response to applications of lime and phosphorus. The experiences of farmers who have treated large acreages have now demonstrated the possibilities of this low cost fertilization.

Small brush constitute a minor problem. Brown (1) has shown that summer cutting is most effective. The program includes cutting the larger brush whenever time is available, and clipping the new shoots in summer. Cutting brush has long been called pasture improvement in this state, but its inadequacy is well shown by Brown and Slate (2).

Because of the large number of animals for the land in tillage and the proportion of this in legumes on some farms, part of the manure must either be put on the permanent pastures or be rather poorly utilized by other crops. There is almost no specific evidence to indicate the relation of manure to pasture improvement. The farmers who have used manure following applications of lime and phosphorus have developed high grade turfs with Kentucky bluegrass and white clover predominating. These pastures, perhaps because they are not grazed so closely, maintain production through the summer and fall much better than the complete fertilizer treatments in the grazing experiment.

Supplemental pastures are badly needed. What little is done in this direction is based chiefly upon farm experience rather than upon more carefully measured results. At least two practices are purposely omitted from the program, *viz.*, attempting to reseed without cultivation and fertilization, and cultivation without fertilization and reseeding. While the reasons for these may be chiefly empirical observations, the definiteness of the experiences leads clearly to the conclusions given.

CONCLUSION

Most publications on the subject of pasture improvement, whether research or extension in character, still begin with the statement that pastures furnish cheaper feed than any other crop, with little and sometimes no proof.

The solution of many pasture problems has been delayed because of the seemingly unsurmountable difficulties involved in experimentation. However, since the acreage of land available for pasture is extremely large and since pasture at least involves low labor cost, the value of pasture, the possibilities for improvement, and the relation of the many factors including management and utilization to improvement should be comprehensively studied without delay. Until much satisfactory information is secured for a given situation, would it not be better to allow the farmer to solve his own problems than to influence him into using uncertain practices?

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OHIO'S PASTURE PROGRAM[1]

E. E. Barnes[2]

The beginning of permanent pasture improvement demonstrations as a major extension project in Ohio dates back to 1920. There was little experimental work to guide us at that time, and in recommending treatments on run-out pastures it was thought necessary to tear up the old sod, lime, fertilize, and reseed. This treatment was found effective but expensive. In fact the expense was so great that it was difficult to find men who would consent to act as demonstrators. Some of the demonstrators did only part of what was recommended. As it turned out, this was fortunate because it showed that some of the more expensive parts of the recommended treatment were not necessary. By 1922, we were convinced that reseeding was unnecessary in most cases and that any tillage operations on the old sod were not only an unnecessary expense but, in some cases, were positively harmful. In that year, the general recommendations were changed to include only the liming and fertilizing program.

Of the different fertilizers tried, superphosphate gave the best returns by way of restoring the old sod to one composed principally of white clover and bluegrass. About this time another fact was brought to our attention by a demonstrator at Mt. Perry, Ohio. He had treated an acre with lime and superphosphate according to our recommendations and then, on his own account, treated another acre without lime but with additional phosphate in such a quantity that he spent as much money on the plat receiving phosphate alone as on the one which received both phosphate and lime. To our astonishment, he obtained better results on the plat which received the extra phosphate but no lime. This led to an investigation of what was the minimum pH value satisfactory for permanent pasture. The results indicated that where the reaction of the soil was pH 5.5 or higher liming did not seem to be necessary or economical. On soils where the reaction was lower than this, liming seemed necessary if the best results were to be secured from the phosphate.

By 1925, a thousand or more demonstrations were under way in the state, mostly in eastern Ohio where the problem was most acute. As an interesting observation, it was noted at this time that a consider-

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Presented as part of a symposium on "An Extension Program for Pasture Improvement" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Associate Agronomist.

able proportion of the wornout pastures in southeastern Ohio could be rejuvenated without the use of lime, while in northeastern Ohio liming was more generally necessary. Instances also came to light, more especially in northeastern Ohio, where some reseeding was necessary. Apparently these soils had supported a poor type of vegetation so long that all desirable plants and seeds of these plants had perished. It should be mentioned perhaps that the soils of southeastern Ohio are residual while those of northeastern Ohio are glacial. Another difference in their origin is that some of the soil in southeastern Ohio has been produced from coal measure rocks which are usually more or less calcareous, while those of northeastern Ohio are derived from non-calcareous sandstones and shales and doubtless were poorer in lime originally than soils of the coal measures.

As a means of getting the results of these demonstrations before farmers, tours and field meetings were held in all counties where this work was in progress. These were quite largely attended and gave an opportunity to enlist additional men in the cause of demonstrating a method of improving wornout pastures. Some attempts were made to measure the effect of treatment by means of grazing livestock. One such case occurred on a farm in Scioto County. Here 10 acres of a 40-acre pasture were treated and divided from the untreated portion by means of a fence. The same number of Angus calves were weighed into the treated 10 acres and the untreated 30 acres and pastured during the season. At the end of the season they were weighed out. The result was that the 10 acres of treated pasture produced more gain on the calves than the 30 acres of untreated.

In a few of the early demonstrations potash was added to the lime-phosphate treatment on a part of the demonstration. In no case was there any improvement visible to the eye from the use of potash. For the last four years an experiment has been under way on the Fry Farm of the Ohio Experiment Station at Wooster. In this experiment the addition of potash to the lime-phosphate treatment has shown no improvement in yield as determined by mowing the plats with a lawn mower and collecting the grass and weighing. We cannot say that there are no soils in Ohio where potash should not be included in the fertilizer used to improve pastures, but we can say that where it has been tried the results from it have not been promising. We are at present planning an experiment to test the response of pastures to this fertilizer ingredient on several of the county experimental farms scattered over the state.

At the time this demonstration work was started and for several years thereafter the price of nitrogenous fertilizer was too high to

make it an economical material with which to treat pastures. Our aim was therefore to treat pastures in such a way as to encourage the growth of native legumes (white clover in northeastern Ohio, and white clover and Japan clover in southeastern Ohio) to secure the nitrogen necessary to grow bluegrass. This scheme was successful, but it was impossible to make a pasture more productive than to require about an acre to carry a 1,000-pound animal through the pasture season. However, this was a great improvement for on untreated pasture it required 4 or 5 acres to carry a 1,000-pound animal. These results were so gratifying that we were content to pursue a policy of recommending the phosphate or phosphate and lime treatment alone, disregarding the possibilities of further improvement by addition of nitrogenous fertilizers to pastures which were as far improved as was possible by means of the phosphate-lime program.

In 1928, in view of the results obtained by means of the Hohenheim system of pasture management in Europe, consideration was given to the possibility of improving pastures still further by treatment with nitrogenous fertilizers. Accordingly, two experiments were started in the state in the spring of 1929 to test its possibilities. One of these is under the direction of the Soils Department of Ohio State University and is located just outside the city limits of Columbus on a dairy farm. The other is under the direction of the Department of Agronomy of the Ohio Agricultural Experiment Station and is located on a farm 5 miles south of Dayton. In this experiment beef cattle are used to eat off the grass. Although these two experiments have only been in progress for the past two seasons, the results to date may be of interest.

The writer is indebted to Mr. Robert Yoder, who is in immediate charge of the Schaff Dairy Farm experiment, for the data presented here in regard to this experiment. The carrying capacity of this pasture previous to the experimental treatment was from 1¼ to 1½ acres per cow, or otherwise expressed, each acre supported from 0.66 to 0.8 cow for a pasture season of 150 days. During the season of 1929, the first year after treatment, the carrying capacity was 1.82 cows per acre for a pasture season of 172 days. This means that the treatment had doubled the carrying capacity and increased the grazing season by about 15%.

The cost of producing increased protein in the pasture grass was only slightly greater than the cost of an equal amount of protein bought in the form of concentrates in carload lots. It is presumed, however, that the protein produced in the pasture grass was of more value as a stimulant to milk production than an equal amount of pro-

tein in the form of concentrates. There is no proof of this tenet, but the matter will be carefully analyzed during the course of the experiment.

The cost per acre of the treatment in 1929 was about $25.00, and the cost of pasture per cow about $3.00 per month. The increase in the carrying capacity was about 1 cow per acre, which would mean that at the above figure the pasture treatment was worth $18.00 per acre for the season plus the cost of some additional concentrates which would have been needed if the pasture had not been treated.

As the experiment stands to date, Mr. Yoder concludes that, "The Hohenheim system is going to be economically sound in this country where one or more of the following factors come into play: (1) A high producing herd of dairy cows sensitive to small changes in feeding; (2) high-priced land; (3) where pasture acreage is limited; and (4) where rainfall is relatively high throughout the pasture season and where rainfall distribution is rather even."

A decline in the price of nitrogen would extend the range over which this system could be economically practiced. It might be added that the dairyman upon whose farm this test is being made has been so impressed with this system that he has adopted it on all his small pastures and calf lots which are not included in the experiment.

The 1920 results obtained on the experimental pasture near Dayton have been published in Ohio Experiment Station Bulletin 446 (pages 20 to 23).

This field was divided into three portions. On one of the sections, the Hohenheim system in all its details was adhered to; while on another section the same fertilizer treatment was made as required by the Hohenheim system, but the field was not divided into small paddocks. On a third section no treatment was made. It is stated in Bulletin 446 that, "The data for the grazing period of May 14 to October 30 show a gain of 179.5 pounds of beef per acre on the nitrated but undivided field, 175 pounds per acre for the field divided into paddocks, and 97.8 pounds for the unnitrated field." This experiment, therefore, shows no advantage in dividing into paddocks and grazing in rotation.

In the present state of our information, we are not in a position to indorse the Hohenheim system to the point of advocating it as an extension project in Ohio. It does not follow, however, that we cannot conscientiously recommend the use of nitrogen on pastures which have been brought to the highest perfection possible by the phosphate-lime treatment, when a greater carrying capacity is needed.

At the present price of nitrogen it would seem that the economical use on pastures is confined to situations where more pasture is needed

and where extending the acreage is expensive because of high priced land, or where more land is not available at any price. If the price of nitrogenous fertilizer were to be materially reduced, the area over which it could be economically used would, of course, be greatly extended. In other words, pasture land in Ohio stands ready to absorb an additional output of nitrogenous fertilizer as soon as the price of the latter makes its use economically sound.

Looking into the future, it would seem that we will continue to indorse the phosphate or phosphate and lime program on all really poor pastures, as has been done in the past. In relatively few instances nitrogen can be recommended as a means of obtaining additional improvement. Further experiments may disclose soils on which potash can be used with profit.

MARYLAND'S PASTURE IMPROVEMENT PROGRAM[1]

F. W. Oldenburg[2]

Aside from the fundamental problem of soil fertility, Maryland farmers have few questions of greater importance than that of pasture improvement. More and more are they looking to dairying as their chief source of income, but it is evident that any further increase will have to be brought about by cheaper production. One of the chief means of reducing costs of production, is improving pastures and managing them better. Some dairymen have learned that pastures suitable for dairy cows, due to their nearness to the barn, will give profitable returns on a considerable amount of time and money spent on their improvement, especially if the extra pasturage makes less barn feeding necessary. The improvement of more distant pastures better suited to beef and other farm animals presents a different problem.

Data on pastures are hard to obtain. In 1918 there was a total of 860,000 acres in pasture in Maryland. This had increased to 898,000 acres by 1925 and is probably greater now. They are divided as follows: Plowable, 529,000 acres; wooded, 189,000 acres; other, 180,000 acres. The carrying capacity is given as 1 cow to 2 acres on the plowable land, 1 cow to about 3 acres on the wooded pastures, and 1 cow to 4 acres on the other land. On this basis the total is equivalent to 745,000 acres of plowable land in carrying capacity.

The number of farm animals in Maryland as given by the 1925 census is as follows: Dairy cattle, 187,000; other cattle, 98,000; horses and mules, 125,000; sheep, 108,000; and hogs, 198,000.

Allowing 2 acres for each head of cattle; 1 acre for each horse, mule, and sheep; and 1/4 acre for each hog, a total of 851,000 acres of pasture is needed. With an equivalent of 745,000 acres there is an apparent shortage of 106,000 acres. These figures give little information as to what part of the pastures are permanent and suitable for dairy cows and what part rotational, or where the shortage is. However, from observation we know that this shortage is principally in the new dairy regions and largely on the Eastern Shore.

Corn and wheat are the principal farm crops on the majority of Maryland farms. More than 500,000 acres of each are grown. The

[1]Contribution from the Extension Service, University of Maryland, College Park, Md. Presented as part of a symposium on "An Extension Program for Pasture Improvement" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Extension Agronomist.

common rotation is corn, wheat, hay, and pasture. On a large proportion of farms wheat is repeated, making a five-year rotation. The extent to which these rotations are followed can be judged by the fact that only a very few states raise more wheat and corn per square mile than Maryland. In northern and western Maryland the early settlers were also livestock growers and organized their farms for grain and livestock with regard to buildings and rotational and permanent pastures. They were no doubt attracted to this region because bluegrass thrived on all the better soils and especially in the limestone valleys. Few have regarded permanent pastures as crop lands to be fertilized and cared for, and as a consequence a large proportion are not much more than exercise grounds for the cows the better part of the year. In this region the problem is to restore soil fertility, where it can be done so profitably, and to bring about better pasture management.

On the Eastern Shore and in southern Maryland the farms were largely organized to grow corn and wheat with one or more intensive cash crops. Little provision was made for cattle in the way of buildings or pasture. On the Eastern Shore the tenant system began to prevail, the landlord getting half of the grain and corn for his share. In recent years dairying has invaded this territory and has now reached the southern counties. In this region the pasture question has additional angles. Aside from those on waste land, permanent pastures are rare. Although the farming system has changed to dairying, the landlord still gets half the grain and corn and nothing else; consequently, it is not to his interest to establish pastures if it involves reducing the acres in corn or wheat. The common rotation followed includes corn followed by two wheat crops. This system is especially favorable to the development of garlic. Generations of this practice have caused the whole area to become infested; consequently, a large proportion of any stand, either in a rotational pasture or in any permanent pasture that may be established, is sure to be garlic. To produce salable milk under these conditions, it is necessary to take the cows off the pasture many hours before milking time. Under this condition the value of the pasture is limited unless it is good enough so that the cows can get all necessary feed in a short time. There is still much to learn as to the best grass mixtures for each of the soil types found in this region and the best system of management.

The aims in pasture improvement work in Maryland are as follows:

I. To restore and maintain the fertility of grass lands that once had a good carrying capacity on farms where the extra feed is needed.

1. By topdressing with superphosphate, adding potash and lime when needed.
2. By topdressing with manure reinforced with superphosphate.

II. For dairymen with limited acreage of pasture accessible to the stable, a more intensive program of fertilization. This involves the additional application of nitrate fertilizer a month or more before the cattle are turned in and a system of pasture rotation and better management.

III. Better pasture management.
1. Avoiding too early and too intensive grazing to give grass a better chance to get a start and to maintain itself.
2. Mowing down pasture weeds at the right time.
3. Harrowing to scatter droppings.
4. Dividing larger pastures, fertilizing, and rotating.

IV. A more general practice of establishing emergency pastures, both for early spring and summer, to supplement the main pasture.
1. For early spring, wheat, oats, rye or barley; second year sweet clover.
2. For summer pasture, (a) sweet clover sown in the spring, separately or in the grain; (b) Sudan grass or other quick-growing hot weather grasses or legumes.

V. Determining the best grass mixtures to establish pastures, both permanent and rotational.

The following agencies will be employed by the extension forces to put across the pasture program:

I. The dairy associations.
II. Cow testing associations.
III. Farm bureaus, granges, and cooperatives in the counties.
IV. Fertilizer and lime industries.
V. Other industries, including canning, farm machinery, etc.
VI. The press.

In regard to the dairy associations, their wholehearted support is expected, especially when pasture improvement does not interfere with their marketing program, that is with the problem of surplus milk. It is not a question of producing more milk, but cheaper milk, by substituting more pasture feeding for barn feeding. Through these organizations the county agents can obtain data that will help them build up their county programs. At the receiving stations they can check up on the dairymens list, on acreage, need of pasture, etc. A seasonal program of publicity in the house organs of these associations, namely, the *Maryland Farmer* for the Maryland Dairymens Association and the *Interstate Milk Producers Review* for the Philadelphia Association. Some of this was done with the former during this season.

The farm bureaus, granges, cooperatives, and other farm organizations in the counties can give facilities for winter meetings and field meetings. Local dealers have the confidence of many farmers who look to them for advice. They are a great help in putting across a project of this kind, and it is important to keep them informed in regard to the latest results and recommendations. Live contacts have been made with most of them in wheat smut work, fertility demonstration work, and the emergency feed program.

Timely articles in the county press will be a big help. The county agents have columns in the local papers where timely articles can appear. More definite plans for publicity can be provided by conferences or publicity specialists, members of the dairy department, and others. Film strips of pasture work can be made with local data. Special pasture programs can be held at the annual meeting of the Crop Improvement Association held jointly with the Dairymens Association, as was done last year, while pasture exhibits can be made at the state fair and other important fairs, calling attention to the pasture problem. Such exhibits were placed at four fairs in 1928.

Pasture improvement is a long time proposition, and in the past it has been difficult to interest many farmers in the question. But with all the agencies now working on the problem and with all the evidence accumulating as to its importance and practicability, a growing number of farmers are expected to follow better methods of pasture improvement and management.

THE PASTURE PROBLEM IN IOWA AND HOW IT MAY BE SOLVED[1]

W. H. STEVENSON AND P. E. BROWN[2]

There are over 10 million acres of pasture land in Iowa, much of which is quite unproductive and gives only small yields of grass of relatively low nutritive value. It is very desirable, therefore, to determine the methods by which unsatisfactory pasture areas may be made more productive and the quality of the grass improved.

PASTURE EXPERIMENTS IN IOWA

During the past few years the Iowa Agricultural Experiment Station has carried on a number of pasture experiments in various parts of the state in order to learn something of the methods which should be followed for the improvement and maintenance of good pastures. The work on these fields, while far from conclusive, does show the desirable effects of discing, of reseeding, and of the application of certain fertilizers. The plan of some of these tests and the results secured will be presented here briefly.

MURRAY FIELD

The investigations on this field in Clarke County, in southern Iowa, have been under way since 1925. The soil is Shelby loam, a drift soil extensively developed in southern Iowa, and considerable permanent pasture areas are located on this type. It occurs on the slopes between the stream bottoms and areas of upland soil, and is developed in strips bordering the slopes of valleys and ravines as well as in some broader and more continuous tracts near the larger streams.

The surface soil of the Shelby loam is a brown to dark brown loam, often containing considerable sandy and gravelly material, to a depth of 8 to 10 inches. The subsoil grades into a brownish-yellow with considerable mottlings, pebbles, and lime concretions. The surface soil is usually acid and in need of limestone, while the subsoil often contains lime.

In topography the Shelby loam varies from sloping and rolling to somewhat hilly. Erosion occurs to a considerable extent in most areas.

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Presented as part of a symposium on "An Extension Program for Pasture Improvement" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

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The plan of the experiment is shown in Table 1. The plats are disced and reseeded every two years with a mixture consisting of 2½ pounds of sweet clover, 2½ pounds of red clover, and 2½ pounds of alfalfa per acre. Superphosphate (16%) was applied at the rate of 150 pounds per acre at seeding time; manure, at the rate of 8 tons per acre, was applied once in four years. An initial application was made of 2½ tons of ground limestone per acre. A portion of each plat is grazed during the entire season, while the remainder of the plat is not grazed until late in the summer. In 1925, the plant growth on the area consisted mainly of timothy with only a sprinkling of red clover and bluegrass in the timothy.

The results for 1930 are given in Table 1 and the data show that manure alone increased the yield less than 0.25 ton per acre. Discing and reseeding were just about as effective as the treatment with manure alone. The application of manure and lime, in addition to reseeding and discing, added a ton to the yield. A quarter of a ton was added to this yield in turn by the use of superphosphate. Discing alone gave an increase somewhat larger than that brought about by the use of manure. Limestone with discing and reseeding increased the yield nearly 1 ton over that secured on the disced and reseeded plat. The disced, reseeded, limed, and phosphated plat gave a yield that was only slightly less than that on the plat that received the same treatments but with manure in addition.

TABLE 1.—*The effect on yield of discing, reseeding, and fertilization, Murray Field, 1930.*

Plat No.	Treatment	Tons per acre*
1	No treatment	1.12
2	Manure	1.32
3	Disced and reseeded	1.14
4	Disced, manured, limed, and reseeded	2.34
5	Disced, manured, limed, reseeded, superphosphate	2.58
6	Disced	1.50
7	Disced, reseeded, manured	1.74
8	Disced, limed, reseeded	2.17
9	Disced, superphosphate, reseeded	1.43
10	Disced, limed, superphosphate, reseeded	2.45
11	Disced and reseeded	1.34
12	No treatment	1.18

*Air-dry basis.

The data presented in Table 2 are of interest because they show that red clover is found on both the limed and unlimed reseeded plats, but no sweet clover or alfalfa grew on any unlimed plat, whether reseeded or not.

TABLE 2.—*Effect of discing, reseeding, and fertilization on the number of sweet clover, red clover, and alfalfa plants, Murray Field, 1930.*

Plat No.	Treatment	Plants per 25 sq. ft.		
		Sweet clover	Red clover	Alfalfa
1	No treatment	0	0	0
2	Manure	0	2	0
3	Disced and reseeded	0	34	0
4	Disced, manured, limed, reseeded	18	36	12
5	Disced, manured, limed, reseeded, superphosphate	24	40	15
6	Disced	0	0	0
7	Disced, reseeded, manured	0	30	0
8	Disced, limed, reseeded	26	28	14
9	Disced, superphosphate, reseeded	0	31	0
10	Disced, limed, superphosphate, reseeded	31	34	20
11	Disced, reseeded	0	28	0
12	No treatment	0	0	0

WINTERSET FIELD

The investigations on this field in Madison County were begun in 1928. The soil is Tama silt loam of loessial origin occurring extensively in south central Iowa. Considerable permanent pasture areas are located on this soil type. It occurs on the more gently undulating to slightly rolling uplands, the areas being found between the various streams and intermittent drainage ways.

The surface soil of the Tama silt loam is a dark brown mellow silt loam extending to a depth of from 8 to 16 inches. The subsoil is a yellowish-brown, compact heavy silt loam to a light silty clay loam, becoming heavier at the lower depths. The surface soil, as well as the subsoil, is acid in reaction and applications of limestone are necessary for the best growth of legumes.

The plats were located on an area that had been in permanent bluegrass pasture for the past 25 years at least. The plats are disced and reseeded every two years with a mixture of sweet clover 3 pounds, red clover 3 pounds, alsike clover 1½ pounds, and alfalfa 2 pounds per acre. An initial application was made of 2½ tons of ground limestone per acre; of superphosphate (20%), 120 pounds per acre at seeding time; and an annual application of ammonium sulfate, 100 pounds per acre.

The results for 1930 are given in Table 3. There was little effect from discing alone and from discing and reseeding, when the yields are figured on an air-dry basis. However, the field records show that the crop harvested on the disced and reseeded plat was about 40% larger than the crop on the disced plat, on a green-weight basis. This difference is no doubt due to the fact that the reseeded plat carried a

fair stand of red clover. The use of lime, in addition to discing and reseeding, increased the yield approximately 0.5 ton per acre. When superphosphate was added the increased yield amounted to 0.1 ton per acre. Ammonium sulfate applied in addition to discing showed little effect on the yield.

The data presented in Table 4 show that no sweet clover or alfalfa grew on any of the unlimed plats. On the other hand, red clover and alsike clover grew quite satisfactorily on all of the reseeded plats.

TABLE 3.—*The effect on yield of discing, reseeding, and fertilization, Winterset Field, 1930.*

Plat No.	Treatment	Tons per acre*
1	No treatment	1.10
2	Disced	1.07
3	Disced and reseeded	1.08
4	Disced, reseeded, limed	1.51
5	Disced, reseeded, limed, superphosphate	1.61
6	Disced, ammonium sulfate	1.15

*Air-dry basis.

TABLE 4.—*The effect of discing, reseeding, and fertilization on the number of sweet clover, red clover, alsike clover, and alfalfa plants, Winterset Field, 1930.*

Plat No.	Treatment	Plants per 25 sq. ft.			
		Sweet clover	Red clover	Alsike clover	Alfalfa
1	No treatment	0	0	0	0
2	Disced	0	0	0	0
3	Disced and reseeded	0	12	2	0
4	Disced, reseeded, limed	11	8	4	7
5	Disced, reseeded, limed, superphosphate	13	11	3	9
6	Disced, ammonium sulfate	0	0	0	0

EXPERIMENTS IN WESTERN IOWA

Pasture improvement work was begun in western Iowa in 1925. A field located on Knox silt loam in the western part of Plymouth County was chosen for this work. Knox silt loam is of loessial origin and is developed on the bluffs bordering the Big Sioux River and the bottom lands of that river, extending into the uplands for several miles in some places. In topography the Knox silt loam is rolling to rough and broken and most areas are typically steep. Most of this land is unsuited to cultivation and remains in pasture and woodland. The surface soil is a grayish-yellow silt loam, extending to a depth of about 6 inches, although much thinner in places. The upper subsoil is a brownish-yellow silt loam, changing to a buff color at the lower depths. The surface soil and subsoil are highly calcareous.

A lack of rainfall in some summer seasons is the chief factor limiting the growth of pasture grasses on such areas of land in this section. In years of normal rainfall, these pasture areas produce considerable feed. The native sod consists of bunch grass, buffalo grass, and bluestem, with a small amount of bluegrass present in the draws and on the lower slopes.

The pasture improvement work begun in 1925 on this area included tests of the effects of discing and reseeding and the use of superphosphate on various plats. The seeding mixture contained sweet clover, alfalfa, brome grass, orchard grass, and bluegrass. Sweet clover made some growth during 1925, but the alfalfa and grasses failed to appear. The same treatments were repeated in 1926, but owing to a very dry season the new seeding failed to become established, except in the case of the sweet clover. Discing benefited the stand of sweet clover to a marked extent and the use of superphosphate increased the growth of the sweet clover.

Beginning in 1927, the plats were disced and reseeded every two years with two seeding mixtures, namely, sweet clover 2½ pounds, red clover 2½ pounds, alfalfa 2½ pounds, and brome grass 1½ pounds per acre; and sweet clover, 8 pounds per acre.

Superphosphate (16%) was added at seeding time at the rate of 150 or 250 pounds per acre, and potassium chloride at the rate of 25 pounds per acre. A portion of the plats is grazed continuously and the remainder kept under control. The data secured for the past four years on this field have shown several interesting facts which may be summarized briefly as follows:

(a) Of the plants in the seeding mixture, sweet clover is the only one that has really established itself. A small amount of alfalfa and brome grass has been found, but red clover has failed to appear. (b) Discing is apparently quite necessary for establishing a stand of sweet clover the first year. The farmers in this part of the state have been accustomed to secure a fair stand of sweet clover in two to three years by reseeding without discing. (c) The average results for the past two years on this field have shown a yield of approximately 1½ tons of air-dry material per acre on the check plats. (d) Discing and reseeding have increased the yield about 1 ton per acre. (e) The application of 150 pounds of superphosphate per acre has proved as effective as 250 pounds and has brought about an increase in the growth of sweet clover of about ½ ton per acre. (f) Potassium chloride has failed to show any effect on the growth of sweet clover. (g) The stand of sweet clover was established equally as well on the grazed area as on that under control.

The general conclusions from this experiment are that discing and reseeding with sweet clover, with a topdressing of superphosphate, have materially increased the grazing value of these pasture areas; and that the addition of sweet clover has increased the feeding value of the pasture, as well as having produced earlier grazing in the spring and superior grazing in mid-summer when ordinarily the native grasses dry up badly.

THE PASTURE EXPERIMENT AT THE AGRONOMY FARM

An experiment was laid out in 1921 on an old bluegrass pasture on a typical area of Carrington loam in the Wisconsin drift soil area on the Agronomy Farm of the Iowa Agricultural Experiment Station at Ames. In this experiment a large number of small plats were laid out. These plats receive various treatments, including discing, reseeding, manuring, and treatment with various nitrogenous, phosphatic, potassic, and complete commercial fertilizers. Additions of lime are also made to half of each plat, when needed. There are three series of plats, one of which is pastured continuously, one is maintained under controlled pasture conditions, and one is unpastured but the grass is cut twice each season. The plan of this experiment and the results secured in 1923 are presented in Circular 89 of the Iowa Agricultural Experiment Station.

The project has been continued and later results have served in a very large measure to confirm the earlier observations. It has been found that discing, reseeding, and manuring or fertilizing old bluegrass pastures on Carrington loam are very desirable practices. The effects of discing with reseeding are outstanding. Manuring is of value and certain fertilizers have large effects upon the character and amount of the pasture growth. The character of the plant growth is quite different under different fertilizer treatments. The results of this experiment as a whole indicate that, on this soil, at least, old bluegrass pastures may be improved and kept in good condition through proper discing, reseeding, and fertilization.

These preliminary experiments in Iowa and similar tests in other states have indicated that certain fertilizers may prove of large economic value in increasing the growth and feeding value of pasture grasses. As a result of these tests, there has arisen an increasing demand on the part of dairy farmers and beef cattle producers for more definite information regarding methods of fertilization and general soil management for their permanent bluegrass pastures, and it is very desirable to carry out more complete studies of the pasture problem under actual pasture conditions.

The following outline of a proposed fertilizer and soil management project for use in a study of permanent pastures in Iowa suggests some of the important factors which we believe should be included in an investigation of this kind.

PROPOSED SOIL MANAGEMENT INVESTIGATIONS ON PERMANENT PASTURES

OBJECTS

To study the effects and value of certain fertilizer treatments on permanent bluegrass pastures on dairy and beef cattle farms and to determine the influence of the treatments on the soil flora, the chemical conditions in the soil, the plant population, and the nutritive value of the grasses.

METHODS OF PROCEDURE

Location

Typical bluegrass pastures are to be selected on dairy and beef cattle farms on soil types which are extensively developed in the state.

Plan of Experiment

Dairy farms. On each pasture selected for this study at least two plats of equal size shall be laid out and fenced, one to serve as a check (untreated) and the other to be fertilized as indicated below. A strip 1 rod in width shall be fenced off across each plat to provide unpastured areas from which samples may be taken for laboratory studies of the soil and herbage. That portion of each pasture that is not included in the experiment plats shall be used as a reserve pasture. Additional plats should be used to vary the fertilizer tests to the extent to which funds for the work are available. The size of the plats shall be approximately such as to give 1 acre of pasturage for every five milking cows in the herd.

Beef cattle farms. In each pasture two or more plats of equal size shall be laid out and fenced, as on the dairy farms, with a strip fenced off as previously described. The fertilization will be the same as on the dairy farm. The size of the plats will be determined by the number and age of the animals in the herd and the supplementary feed used.

Fertilization

Discing. The plats shall be disced as early in the spring as conditions permit and prior to fertilizer application.

Lime. If the soils show acidity, sufficient lime shall be applied on one-half of each check and fertilized plat in an amount sufficient to neutralize the acidity in the surface soil.

Commercial Fertilizers

Complete commercial fertilizer. Approximately 200 pounds of a high-grade, complete commercial fertilizer are to be applied to the fertilized plats immediately following discing.

Nitrogen. Twice during the season, namely, about the first week in June and about the first week in September, the fertilized plats shall be topdressed with 100 pounds per acre of a high-grade nitrogenous fertilizer.

Method of Pasturing

The milking herd or beef cattle herd shall be pastured on the fertilized plat beginning in the spring when the grass appears to be in optimum condition and pasturing shall continue on this area as long as conditions are favorable. The herd shall then be transferred to the check plat, if the grass on that area is in optimum condition, and continued there as long as conditions are favorable. If the check plat is not in condition to receive the herd when it is taken from the fertilized plat, the reserve pasture shall be used until the check reaches optimum condition.

Determinations of Pasture Days, Milk Production, Supplementary Feeds, and Weight of Animals

Pasture days. A record shall be kept of the number of days the cows are on each plat and the number of days they are on the reserve pasture.

Milk production. Records shall be kept of the daily milk production.

Supplementary feeds. Daily records of supplementary feeds shall be kept.

Weight of animals. All the animals in the experiment shall be weighed at the beginning of the grazing season and when transferred from one pasture area to another.

Laboratory Studies

Soil flora. The content of bacteria, molds, and actinomycetes shall be determined in samples from the fertilized and unfertilized plats at intervals during the season. The nitrifying power of the soil shall be determined at intervals during the season. The nitrogen-fixing flora of the soil shall be determined by the Winogradsky method.

Chemical conditions of the soil. The pH of the soils on the plats shall be determined before fertilization and at the beginning and end of each grazing season, also at all times when samples are drawn for bacteriological tests. The nitrate content of the soils shall be determined at intervals in connection with the nitrification tests. The amount of exchangeable bases in the soil shall be determined at least twice each season. The available phosphorus content of the soils shall be determined by new qualitative tests at least twice each season and the results checked against grass yields and other data.

Plant population. The plant population shall be determined in the field prior to fertilization and at intervals during the grazing season, both in the grazed and fenced portions of the plats.

Nutritive value of grasses. The protein content of the grasses in each plat shall be determined on samples taken when the pasture is in optimum condition.

Weight of grass. The dry weights of the grass produced on the fenced and grazed portions of a given plat shall be determined with samples taken at the time the herd is turned on that plat.

ORGANIZATION AND COOPERATION

It is proposed to carry on this work on farms in the dairy and beef cattle sections of the state in cooperation with interested farmers. The farmers will furnish the permanent bluegrass pasture areas and the required number of dairy cows or beef cattle. The Soils Section will furnish and apply all fertilizing materials and will furnish materials for fences and erect the same. During the grazing season the Section will keep a trained man on the farm of each cooperator; the Section representative will supervise all the details of the work and secure the desired field data. The bacteriological and chemical studies will be made in the Soils Section laboratories.

Finally, it may be emphasized that there are many extensively developed soil types in Iowa, as in other states, and the problem should, therefore, be attacked on farms located in various parts of the state on individual soil types. Hence, it seems desirable to establish as many experimental fields as can be handled with the funds which may be made available for the project. This outline is presented in the hope that it may call forth some helpful suggestions regarding a set-up for pasture investigations in the corn belt.

QUALITY TOBACCO IN MASSACHUSETTS[1]

R. W. DONALDSON[2]

The purpose of this paper is to state somewhat in brief the general practices now followed by tobacco growers in the Connecticut Valley section of Massachusetts, to indicate certain problems confronting the grower in the production of quality tobacco, to summarize the nature and recent findings of tobacco investigational work as it pertains to this section, to state the mediums of contact between the farmer and the research worker which obtains at present in Massachusetts for the dissemination of information, and to suggest the scope for an Extension program to supplement the research work in securing the adoption of those practices recently found to be practical.

Tobacco is a highly specialized crop, the value of which is particularly associated with quality. Distinctive soil characteristics, as well as climatic conditions, primarily determine the types of tobacco which may be grown and the purposes for which they are eventually used. Because of the effects of soil and climate, the region lying within the Connecticut Valley is one of several in the United States specializing in the raising of tobacco for cigars.

The tobacco soils of Massachusetts may be designated in general as being fine sandy loam the result of alluvial and lakeside deposits.

Tobacco growers in this region of relatively light soil fertilize heavily. Unlike certain other tobacco areas, good quality may accompany high yields in this district. The general practice among growers is to apply 3,000 to 4,000 pounds to the acre of fertilizer which would approximate a 6-3-6 ratio. Where manure is available, it is used commonly in addition to the fertilizer mentioned, and tobacco stalks often are returned to the land.

The fertilizers used for tobacco generally are made up to supply about half of the total nitrogen from organic materials of which cottonseed meal and castor pomace are most commonly employed. Concerning the various other carriers of plant food used to supplement cottonseed or pomace, there exists a considerable range of materials supplying nitrogen, phosphorus, potassium, and magnesium. Mention should be made in this connection of three materials, perhaps the most extensively used in other crop fertilizers, against which the tobacco grower is prejudiced because of a belief in

[1]Contribution from the Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass. Presented at the annual meeting of the Society held in Washington, D. C., November 21, 1930, as part of a symposium on "The Production of Quality Tobacco." Received for publication November 21, 1930.

[2]Extension Agronomist.

adverse effects on quality or burn. These materials are muriate of potash, sulfate of ammonia, and the lower grades of superphosphate.

Regarding the ratio and grade used, a 5-4-5 has been most common. The tendency now appears to be toward a higher analysis, lower phosphoric acid mixture of a 2-1-2 ratio of which the 6-3-6 is the present minimum grade for New England as accepted in principle by the National Fertilizer Association. Higher analysis formulas, such as a 7-4-7, 8-4-8, and 10-5-10 are now being sold in increasing tonnage for use at the rate of 1 to 1½ tons per acre. A 14-7-14 for use at the rate of about half a ton to the acre, together with an equal amount of cottonseed meal or castor pomace or half amounts of each, also is being sold.

Differing somewhat from the principle of rotation as practiced with ordinary farm crops, the tendency in Massachusetts has been away from rotation and more toward continuous tobacco. True, a large number of growers alternate tobacco occasionally with some other cash crop. Some grow cover crops to plow under. Relatively few in recent years are obtaining satisfactory tobacco in a rotation with hay and silage as preceding crops. Survey figures obtained in 1924 indicated at that time that approximately 58% of the farmers visited grew tobacco more or less continuously, while 65% grew cover crops. Contrary to other crop rotation practice, the growers of the Valley stick pretty closely to certain fields as tobacco land where the crop is grown year after year, except for occasional alternation with a cash crop or hay, while in some cases inter-season cover crops are being grown.

Among the problems confronting tobacco-growers of the Connecticut Valley, particularly with regard to quality and yield, may be mentioned the following: What is the effect, particularly upon quality, of the increased use of fertilizers needed to replace manure? Which materials furnish the best fertilizers for tobacco? What practical control measures may be adopted to combat the more serious diseases? Is it possible to secure strains of tobacco similar to present types for yield and quality, but more resistant to the disease of black root rot? What cover or rotation crops, if any, are necessary, or may be grown? Should tobacco fields be limed?

TOBACCO STUDIES

FERTILIZER INVESTIGATIONS

Six years of an experiment being carried on at the Massachusetts Experiment Station with manure and fertilizer as against fertilizer alone for tobacco are recorded in the report of the Station for 1929.

The results thus far indicate that a very slight superiority can be claimed for the manure used in conjunction with fertilizer as compared with tobacco grown with fertilizer alone. Similar results are being noted at the Tobacco Field Station in Connecticut. In their experiment the manured plats are fertilized at two rates of 20 and 40 tons to the acre, while equal amounts of fertilizer are used on the manured plats and on plats without manure.

Records to date of four years show better yields and quality on manured plats during the second and third years, but no appreciable difference during the first season when the rainfall was light and much the poorest tobacco on the manured plats the last season which was excessively dry. Within the limits of these experiments the inference is drawn that manure usually benefits the crop, but if the supply is limited or expensive, good tobacco may be grown without it, except for shade tobacco where even high-priced manure may be justified.

Numerous tests to determine which of the various commercial organic and inorganic materials or combinations provide the best source of nitrogen have been attempted. Because of varying soil and seasonal factors, the problem is still chiefly a matter of research.

As between a fertilizer derived entirely from organic material, such as cottonseed or castor pomace, and a fertilizer supplied from inorganic sources, as nitrates or ammoniates, the older experiments at the Massachusetts and Connecticut stations showed in favor of organics, particularly in their effect upon the quality of tobacco. Materials like cottonseed meal, castor pomace, and linseed meal seemed slightly preferable to fish meal or tankage. These experiments further indicated that, in consideration of relative cheapness, inorganic carriers may advantageously supply half of the nitrogen.

Experiments in progress at the Massachusetts Station, dealing with the amount of applied nitrogen per acre are reported for 1929 as follows: (1) In the absence of barnyard manure, 150 pounds of ammonia per acre is the minimum for tobacco. (2) A somewhat better yield has been obtained from 200 than from 150 pounds, and for many fields the larger application may be nearer the optimum. (3) Although in previous years 250 pounds of ammonia produced slightly superior yields, in 1929 it gave no better yields than the 200-pound treatment.

Tests of nitrogen carriers including cottonseed meal, castor pomace, nitrate of soda, sulfate of ammonia, nitrate of lime, urea, and calurea are now in progress at the Connecticut tobacco sub-station. The results thus far are not conclusive. Indications point to a variable response of tobacco to any of the particular nitrogenous fertilizers, de-

pending largely on soil reactions and upon the seasonal factors of rainfall and temperature. Sulfate of ammonia may tend to adverse burning quality where excess sulfate becomes a factor. On the other hand, urea, calurea, and the nitrates of potassium, lime, and sodium seem in general desirable materials.

Tests conducted at the Connecticut tobacco sub-station show that the plats receiving the smallest quantity of phosphorus produced tobacco with the highest fire-holding capacity, while plats which received the heavy application showed the poorest fire-holding capacity. These results indicate that heavy applications of phosphorus to old tobacco land may affect to some extent the fire-holding capacity of the tobacco and should be avoided. On new land or land which has not been liberally fertilized, some phosphorous may be advisable. Precipitated bone is one of several standard sources of phosphoric acid other than what normally is supplied in cottonseed meal, castor pomace, or in the smaller amounts of fish meal which may be used. Ordinary superphosphate is avoided because of possible excess residue of sulfate being left in the soil which for tobacco has been associated with poor burn.

The potash requirement of tobacco is very high when compared with other agricultural plants. A good potash supply is essential not only to growth, but also the presence of an abundance of potash in the proper combination in the leaf is the most important factor in producing good combustion. The object of potash fertilization, therefore, is to get the plant to absorb as much potash as possible, but at the same time to keep the sulfur content low and to be even more particular to eliminate excess assimilation of chlorine because of the adverse effect on burning.

Years ago New England growers abandoned the use of muriate of potash because the chlorine was thought to ruin the burn. We are indebted to the Connecticut Station for extensive experiments still in progress for tests with various potash carriers which include sulfate of potash, nitrate of potash, carbonate of potash, sulfate of potash-magnesia, and of several by-products supplying potash. Although final results have not yet been obtained, some of the conclusions to date are of interest, as follows: (1) When all potash is omitted from the fertilizer, the grading of tobacco is affected, beginning with a decline the first year and rendering the leaves worthless in about three years. (2) Reducing the potash has not seriously affected the yield but has reduced the percentage of potash in the leaf and has adversely affected the fire-holding capacity of the tobacco. (3) Potash at the rate of 100 pounds per acre is not sufficient to maintain quality,

but as yet no benefit has been observed from raising the amount to 300 pounds. (4) The substitution of sulfate of potash-magnesia for high-grade sulfate of potash has been of no advantage on soil where tested, but may be beneficial in preventing sand-drown or magnesium deficiency in lighter soils. Its use increased the sulfur content, lowered the grading and fire-holding capacity of the leaves, and has not increased the yields. (5) In comparing sulfate, carbonate, and nitrate of potash, carbonate gave the best grading and burning, but the lowest yield; nitrate was satisfactory from these standpoints, but owing to its additional high nitrogen content it should not be used in excess; while sulfate increased the sulfur content in leaves more than did carbonate or nitrate. (6) Most consistently good results were secured from a combination of the three sources of potash, deriving one-third of the required potash supply from each carrier.

The occurrence of sand-drown, a malady characterized by mottling which first attacks the lower leaves, may be present on the lighter soils during seasons of heavy rainfall. Caused by magnesium deficiency, its prevention is possible by supplying magnesia in the fertilizers. Experiments conducted by J. P. Jones of Massachusetts, and also cooperative tests by the U. S. Dept. of Agriculture, and the Connecticut Station, show the necessity for including magnesia in the fertilizer mixture, particularly when the trend is toward more concentrated materials. If magnesia is deficient in the soil and is not supplied in the fertilizer, both yield and quality of the cured leaf may be greatly lowered. Where the tests were run, 30 pounds of magnesia have been sufficient to prevent sand-drown, but a number of instances occurred where 15 pounds were not sufficient during a wet season on these particular soils.

Cottonseed meal carrying 1% and castor pomace with 0.8% of magnesia help to maintain the requirement, depending upon the amounts being supplied. Additional magnesia usually is recommended in fertilizer mixtures supplied either through a high dolomitic limestone or possibly through the use of small amounts of sulfate of potash-magnesia.

DISEASE CONTROL

Investigational work has shown that seedbeds are important sources of infection for several important diseases which spread later in the field causing losses. The use of disease-free seed, soil, and equipment is of special importance. Disinfection followed by dusting or spraying of seedlings is advisable against wildfire, and additional field

sanitation methods also are suggested to prevent contamination by this disease from unrotted previous crop refuse.

The organism causing black root-rot, however, usually is prevalent in fields limed above pH 5.8 It is best to avoid planting such fields or else to use a root-rot resistant strain such as Wisconsin 142. Work is under way to develop strains more resistant to black root-rot. Brown root-rot, which causes stunting similar to black root-rot and often is confused with it, is an entirely different disease, the exact cause of which is unknown. There is much evidence that a preceding crop may cause it, particularly crops like corn, clover, or timothy. Certain fertilizers, soil amendments, or toxins have been demonstrated in experiments to produce similar symptoms, which may or may not be similar to those occurring in the field. All soils do not react alike to the same apparent causal agents, that is, on some soils normal crops of tobacco may grow on sod land, while in adjacent fields the crop may be a failure. Its effect may only be temporary, being more severe the first year following sod than in the second or third year. It may be eliminated by steaming the soil or by aerating it thoroughly.

EFFECT OF OTHER CROPS ON TOBACCO

Since injury from brown root-rot of tobacco appears intimately associated with certain preceding crops, investigational work with various crops and rotations is being carried on in Massachusetts and Connecticut to find which crops may or may not be grown along with tobacco. Final conclusions do not appear consistent. Evidence points, however, toward continuous tobacco as being the most satisfactory, while tobacco following forage crops appears the least satisfactory practice. The practice of rotation with cash crops or the use of cover crops generally should be avoided, but under certain conditions may be justified.

LIME FOR TOBACCO

Lime may be beneficial, injurious, or of no effect, depending upon the acidity of the soil. Investigations have been made both in Massachusetts and Connecticut upon which the following conclusions are based: (1) Liming strongly acid soils has been found to improve the yield, the burn, and the whiteness of ash of tobacco. (2) Soils nearly neutral or alkaline, on the other hand, are those most favorable to black root-rot infestation. (3) A soil reaction between pH 5.0 and 5.6 is optimum for best tobacco. (4) Soils between pH 4.6 and 5.0 require alkaline-forming fertilizers or the occasional use of limestone up

to 1,000 pounds per acre. (5) Soils below pH 4.6 may be limed 2,000 pounds per acre. (6) Soils above pH 6.0 are not safe for tobaccos subject to root-rot.

AN EXTENSION PROGRAM FOR TOBACCO

Up till now, work with the tobacco growers has not been attempted by the Extension Department in Massachusetts. The assistance which the college has been able to render this group has been obtained chiefly through direct contact with the research workers of the experiment station which is conveniently located in the tobacco area. Furthermore, the station has been particularly fortunate in having among its workers on tobacco research an agronomist and a pathologist both of whom did considerable individual contact work among the growers.

It is believed that the Extension Service could supplement the efforts of the experiment station in its service to tobacco growers. This belief has arisen in view of the following recent developments: (1) A request for extension aid has recently been expressed by local growers. (2) Sufficient evidence recently has been secured from investigational work on certain problems to warrant their adoption as farm practice. To effect adoption of recommended practices is the function of extension work. (3) The services of an extension pathologist have become available for the first time through the recent appointment of a specialist in this field. (4) It is believed that, in a measure at least, the extension agronomist and the extension department of farm management also may assist.

SUGGESTED PROJECTS

1. Service on disease identification and control measures.
2. Seedbed disinfection.
3. Soil testing service for pH reaction having particular reference to securing optimum reaction for best growth and evidence of trouble from black root-rot.
4. How to grow potatoes or similar cash crops on acreages recently being withdrawn from tobacco production.

TEACHING METHODS

These should aim to arouse interest, inspire confidence, and secure action. As a sound basis upon which any future program may be evolved, it is the writer's conviction that to work through organized local committees would be good policy. It is proposed to call together in each community a few of the most interested growers and to ask them to select and to sponsor projects they believe most helpful. Having obtained their approval, the responsibility for organization of such work

and the calling of meetings should rest largely with the committee; but the actual detail of the project work would be performed by the extension specialists and the county agents and would consist of circulars, news items, personal visits, and demonstrations. By enlisting the interest and actual cooperation of leaders in one or more of these preliminary projects, it is believed that opportunity will be given to get better acquainted with the industry, to develop confidence among its people, and to make still more effective the valuable contributions of tobacco research.

NOTE

THE OLDEST SOIL MAP?

In the report on the Geology of Massachusetts by Edward Hitchcock, published in 1841, occurs a prototype of our present-day soil map. Although this map in a sense is primarily a geological map, it was undoubtedly meant to be considered a soil map. In Part I of the report, devoted to Economical Geology, Hitchcock wrote, "The commissions with which I have been honored by the Government, for a Survey of the geology and Natural History of Massachusetts, have directed my attention to the following leading objects. First, to collect, examine, and analyze, all the varieties of our soils; and to suggest means for their amendment."

Further, he said, "Hence we should expect, and in fact we find, a corresponding difference in the soils resulting from their (rocks) decomposition. Indeed, with some exceptions, the geologist is able to ascertain the nature of the rock from the character of the soil that covers it. And I apprehend that it will not be difficult to point out the characteristics of the soils derived from the different rock formations of Massachusetts, so that they can be distinguished by those not familiar with practical geology. This Geological Classification is the only one which I shall attempt to give of our soils; and this seems to me all that is necessary, or useful, in addition to the common division into sandy, clayey, loamy, calcareous, etc. The following list embraces, it appears to me, all the important varieties of soil in Massachusetts.

" 1. Alluvium; from rivers; peaty
" 2. Diluvium; sandy and gravelly; argillaceous
" 3. Tertiary soil; argillaceous; sandy
" 4. Sandstone soil; red; gray
" 5. Graywacke soil; conglomerate; slaty, gray; slaty, red
" 6. Clay slate soil
" 7. Limestone soil, magnesian; common
" 8. Mica slate soil
" 9. Talcose slate soil
"10. Gneiss soil; common; ferruginous
"11. Granite soil
"12. Sienite soil
"13. Porphyry soil
"14. Greenstone soil

"In general, if any one wishes to know where to find them, let him look at the Geological Map that accompanies this report, and he may conclude that the different soils cover those portions of the surface that are represented as occupied by the rocks from which they are derived. There is one circumstance, however, that prevents us from considering the boundaries of the rock formations as perfectly coincident with those of the soils. Diluvial action has removed nearly all the loose covering of our rocks in a southerly direction; often several miles; and more or less mingled the soils from different formations."

The map referred to is 18 x 28 inches, and is hand colored to show the rock and soil formations.

The above was written before the glacial hypothesis of Agassiz had been advanced, and the diluvium mentioned is what we now designate as glacial till. It is interesting to read Hitchcock's discusson of the diluvium and diluvial action and note how unsatisfied he was with such explanations as were then available of this phenomenon. However, after the report was written, but before final publication, word was received by Hitchcock of the glacial hypothesis, and it is to his everlasting credit that he was both able to see how well the hypothesis fitted the facts as he saw them in Massachusetts, and that he was liberal minded enough to accept the new viewpoint.

The present writer is of the opinion that this map of Hitchcock's is the first map on which any one attempted to show the classification of soils over any considerable area. If anyone knows of an earlier authentic soil map, the writer would be pleased to hear of it.—A. B. BEAUMONT, *Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass.*

BOOK REVIEWS

CROP PRODUCTION

By H. D. Hughes and E. R. Henson. New York: Macmillan Co. X + 816 pages, illus. 1930. $6.

The first 12 chapters of this book, covering 298 pages, treat of such topics as the world distribution of crops, crop distribution in the United States, how plants grow, root, water, and soil relations of field crops, cropping practices and soil productivity, the seedbed and its preparation, cultivation, and seed.

The presentation of the material dealing with crop distribution and choice is particularly strong. The thinking reader can not help but see what seem to be the important factors in determining crop diffusion throughout the world and in the United States, and he must be impressed with the importance of not permitting prejudice or preference to play too large a part in choosing crops for production within any given area.

To the best of the reviewer's knowledge this book presents more completely than any other of its kind the information that should be at the command of one whose aim is to be well informed on field crop production in our northern states. About the only conspicuous omissions are hemp, field beans, cabbage, and canning factory peas,

Some of the crops grown in small areas in common rotations, such as teasels and tomatoes, might have had passing notice as well.

The book has been prepared for teaching by the problem method. It, therefore, aims, and is very successful in so doing, to present crop production matter from experimental evidence, without opinion or conclusion. Generally, there is only comment enough to set forth clearly the conditions of the experiment, but references to the literature cited are included so that the reader who desires to do so may readily go much farther afield on any topic that the limits of a book would permit. In keeping with this purpose each chapter is followed by some study questions dealing directly with the subject matter presented, but nevertheless questions which cannot be answered by referring to that subject matter only. The use of cross references is necessary. There also are following each chapter some application assignments. These assignments are aimed to provoke group discussion or to cause the individual to find out for himself what is the meaning and significance of what is given in the text. In many cases a full consideration of these application assignments would call for much knowledge of fundamental studies, such as botany, chemistry, and physics, as well as knowledge of the applied sort obtained by soil, fertilizer, and crop study. Thus the book by means of the practical field it covers may stimulate interest in the fundamental scientific explanation of basic processes. On this account the material presented in considerable detail in the first eight chapters may be justified as a background against which the usual student first taking crop work in college may work or by means of which he can come to a partial understanding of some basic processes.

In addition to serving excellently for use in the problem method of teaching, the book is well adapted for use in the assignment-discussion method or the text-reference method of instruction. Besides it is well suited for the general reader or the specialist who wishes to have at hand complete, authoritative, down-to-date information on many phases of common field-crop production. ((J. H. B.)

A TEXTBOOK OF PLANT PHYSIOLOGY

By N. A. Maximov. Translated from the Russian by A. E. Murneek and R. B. Harvey. New York: McGraw-Hill Book Company. XVI + 381 pages. 1930.

Plant physiologists will welcome the fact that this work is now available in the English language. Although the book has been translated through the efforts of Professor Maximov by students at Leningrad, still the editing of the book by Dr. A. E. Murneek of the University of Missouri and Dr. R. B. Harvey of the University of Minnesota has assisted materially in making this text a little more American than otherwise. Dr. Murneek is well acquainted with the Russian language and Dr. Harvey, having spent some time in Maximov's laboratory, knows the Russian viewpoint.

The book has been divided into four parts, as follows: (1) Absorption of matter and energy, (2) water relations of the plant, (3) utilization of reserve products and liberation of energy, and (4) growth,

movement, and reproduction. The book contains 12 chapters and each chapter is divided into distinct topics, 105 altogether. The comparative short chapters with their subdivided, consecutively numbered topics lend themselves readily to class room assignment.

The outstanding process in plants, the absorption of carbon and accumulation of plentral energy, is the first chapter in this text. The first topic is the "Source of carbon for the plant, Method of artificial cultures." In the first topic one comes in contact with one of the outstanding virtues of this text, namely, the citation of definite experiments by certain authorities who were pioneers in the field.

There are no references in the text. However, there is a list of reference books and periodicals in plant physiology which are written in English. It is recognized that elementary students are not prepared to read in any other language than English. It often happens that a single course in plant physiology is all that many plant science students have. It would seem, therefore, that citations of certain standard foreign journals might help to show our students that there is a good deal of work done in other countries besides our own, and that "science knows no boundary lines."

This text presents in a clear, concise, and interesting way the fundamentals of plant physiology. There is no doubt but that a person who studies this book will have a clearer understanding of the intimate relation existing between agriculture and plant physiology. (A. L. B.)

AGRONOMIC AFFAIRS

PENNSYLVANIA'S SOIL FERTILITY CONFERENCE

Commemorating the fiftieth anniversary of the soil fertility plats at the Pennsylvania State College, the College and Experiment Station staff, assisted by eminent soil technologists of other institutions, will present a technical program based on many detailed studies of these old plats on June 24, 25, and 26.

There will be two half days devoted to technical papers, two half days to excursions over the plats, College farms, and outlying soil fertility projects, and one half day to an open forum on soil fertility problems. Special soil fertility inspection trips to the orchard and gardens will be arranged. Dr. W. H. Jordan, who laid out these old plats 50 years ago, will be the guest of honor and will give an address.

An official program will be issued three months in advance of the conference. Invitations will also be sent to all of the Land Grant Colleges, the U. S. Dept. of Agriculture, and to other research agencies, including many prominent soil technologists in the United States, Canada, and European countries. The conference will not be limited to invitation; a cordial welcome is extended to all those interested.

JOURNAL

OF THE

American Society of Agronomy

Vol. 23 — April, 1931 — No. 4

SOME CHARACTERISTICS OF AN ERODED SOIL[1]

G. W. Musgrave and Henry Dunlavy[2]

It is generally recognized in the black waxy belt of Texas that soil erosion is accompanied by decline in crop yields. At Temple, during the 1930 season, an artificially eroded plat produced but one-eighth as much cotton as adjoining uneroded plats. It is also a matter of common knowledge, though perhaps less generally recognized, that the tillage practices commonly followed by farmers in the production of cotton, corn, sorghum, and other row crops encourage erosion. The greater losses of soil and of surface water as runoff from land growing row-spaced crops in contrast to those growing grasses, clover, or small grain have been shown by several workers.

The purpose of the present study was to determine the more important effects of the common practice of growing cotton continuously and of the accompanying soil erosion upon some of the physical properties of the soil.

METHODS

For this purpose an area was chosen for study which has a slight fall and a slight but gradually increasing amount of erosion extending in one direction across the field. It is 1 acre in size and is normally planted in 110 rows which run across or at right angles to the direction of slope. The area represents one of the Texas Blacklands Sub-station acre plats, and was devoted to a cotton variety test during the season these data were collected. In this test every third

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture and the Texas Agricultural Experiment Station, cooperating. Presented as part of a symposium on "Cultural Changes in Soils" at the joint meeting of the Society and the American Soil Survey Association held in Washingon, D. C., November 20, 1930. Received for publication November 21, 1930.

[2]Scientist in Soil Erosion, U. S. Dept. of Agriculture, and Superintendent, Sub-station No. 5, Temple, Texas, respectively.

row was used as a check (same variety) row and the yields are a matter of record.

A soil profile map was made, covering a soil section extending in the same direction as the slope. The surface points of the profile were established by the use of a surveyor's level, and the depth of the several soil horizons was measured from known elevations.

Soil samples were taken in duplicate for the determination of soil moisture during both wet and dry periods through the season; six samples for the measurement of the water-holding capacity of the soil; and composite samples for physical studies, including colloids, moisture equivalent, organic matter, and mechanical analysis. Each

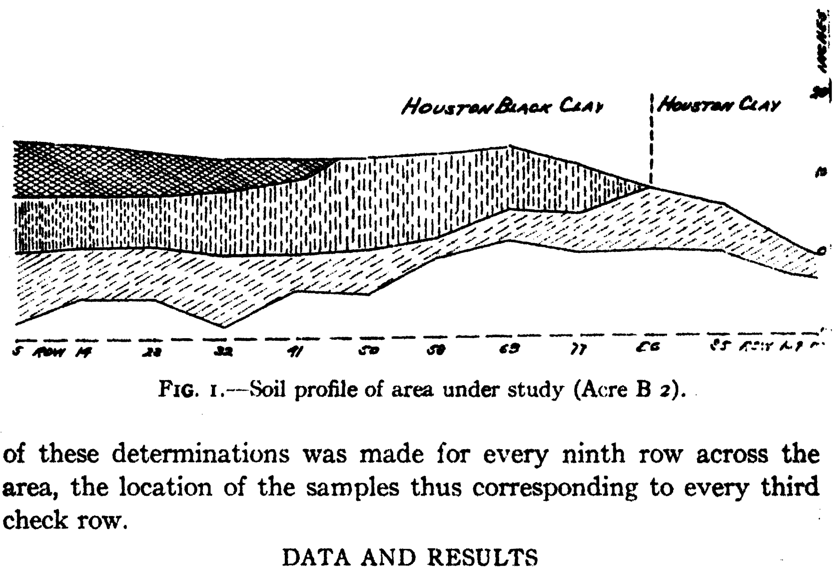


FIG. 1.—Soil profile of area under study (Acre B 2).

of these determinations was made for every ninth row across the area, the location of the samples thus corresponding to every third check row.

DATA AND RESULTS

The topography of the area is shown by the diagram of the soil profile (Fig. 1). That portion represented by rows 5 to 68, a distance of 189 feet, has a total fall of 1 inch. From row 68 to row 107, a distance of 117 feet, the fall is 14 inches. Thus the steepest slope is slightly less than 1% and the entire area has an average fall of only 0.4%.

The profile shows how sheet erosion has occurred in the past, this having progressed to a degree on the lower slope such as to designate the soil as a Houston clay, in contrast to the Houston black clay on the more nearly level upper portion of the acre. However, close observation in the field shows the Houston black clay to be somewhat darker, more waxy, and heavier in texture over the first 40 rows than on the succeeding area approaching the slope. Measure-

ments of the depth of the "black waxy" surface layer, of the slightly brownish-black subsurface layer, and of the brownish-yellow third horizon were made on each third check row across the field. The lowest horizon shown in the diagram represents the subsoil lying immediately above the parent material.

It is seen that none of the yellow subsoil is exposed to the surface; and the field, by contrast with other fields in the region, has both a moderate slope and a moderate degree of erosion. The darker

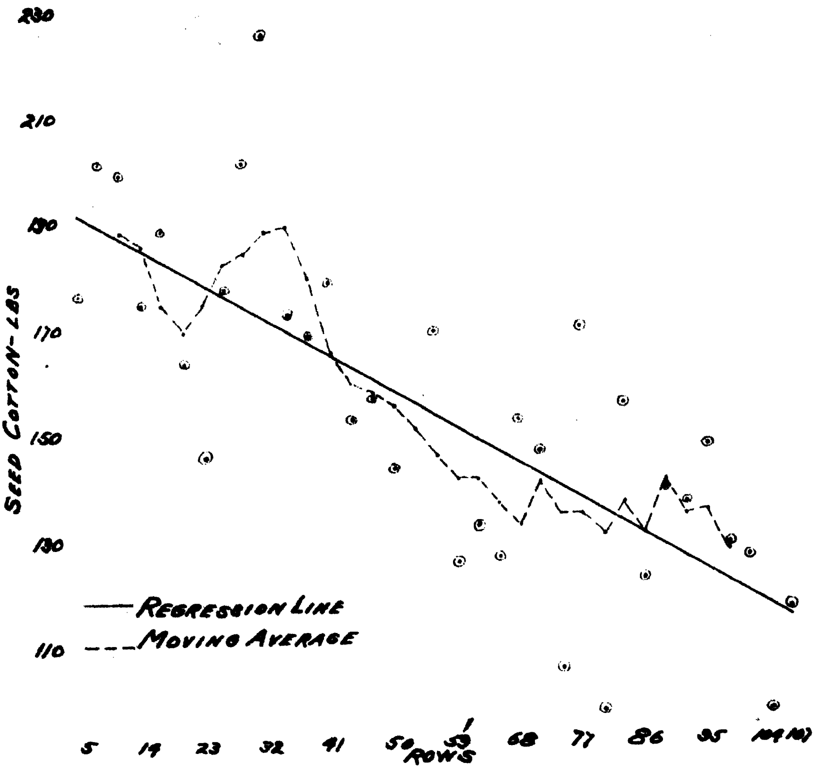


FIG. 2.—Scattergram and regression line of yields of cotton for check rows.

colored portions of the soil, however, have been removed in increasing amounts from row 5 to row 107.

A scattergram and regression line of yields of cotton for each check row is given in Fig. 2. There is also included a five check-row moving average of yields. As might be expected, the yields for the individual rows fluctuate considerably, yet it may be seen that there is a definite trend toward lower yields extending from row 5 to row 107 which lies at the lowest part of the acre plat. The moving average shows this trend clearly, while the regression line indicates the aver-

age decline to be at the rate of 0.75 of a pound for each field row, or about 7 pounds for each third check row on which the succeeding soil studies are based. Obviously, there is a definite relationship between the soil profile previously described and the cotton yields actually produced upon the field.

Soil moisture determinations across the field have been made, using duplicate samples for each of the rows under consideration. Two sets of these determinations are shown in Table 1. The first of these gives the percentage of moisture following a prolonged dry period. For a three-month period prior to these determinations there were but seven light rains, none of them as heavy as 0.25 inch and all totaling but 0.58 inch. The second set of determinations was made three days following a rain of 1.83 inches and one day after a rain of

TABLE 1.—*Soil moisture determinations across the field under study (Acre B2).*

Row No.	Depth, inches	Per cent	Per cent	Weighted average	Row No.	Depth, inches	Per cent	Per cent	Weighted average
Percentage moisture following prolonged dry period (3 months no rain equal to 0.25 inch)									
5	0–6	13.02	10.04		68	0–6	8.50	8.15	
	7–12	21.69	22.70			7–12	16.77	17.81	
	13–24	18.64	23.71			13–24	15.28	16.47	
	25–36	17.47	21.82	19.24		25–36	12.24	42.69	13.71
14	0–6	19.47	9.45		77	0–6	6.51	5.09	
	7–12	23.33	22.36			7–12	15.12	16.29	
	13–24	20.22	23.28			13–24	14.63	14.98	
	25–36	17.81	22.29	20.15		25–36	9.22	12.17	12.08
23	0–6	17.72	9.90		86	0–6	7.43	5.63	
	7–12	22.62	22.76			7–12	13.74	14.38	
	13–24	20.59	22.27			13–24	12.07	11.71	
	25–36	18.14	21.17	19.78		25–36	9.59	7.26	10.20
32	0–6	11.56	11.13		95	0–6	11.96	7.39	
	7–12	20.22	22.11			7–12	12.91	12.39	
	13–24	19.71	21.27			13–24	12.42	10.53	
	25–36	16.61	19.93	18.34		25–36	9.81	9.04	10.69
41	0–6	13.89	11.33		104	0–6	6.07	4.61	
	7–12	20.45	18.22			7–12	13.03	13.15	
	13–24	18.45	19.53			13–24	12.32	12.67	
	25–36	15.59	18.74	17.38		25–36	11.21	11.57	11.03
50	0–6	13.14	6.98		107	0–6	7.57	4.75	
	7–12	19.38	20.17			7–12	13.40	12.02	
	13–24	17.94	19.14			13–24	11.73	12.23	
	25–36	12.98	16.17	16.01		25–36	9.67	10.88	10.56
59	0–6	7.18	9.64			—	—	—	—
	7–12	16.01	17.74			—	—	—	—
	13–24	17.43	14.45			—	—	—	—
	25–36	13.74	11.23	13.52		—	—	—	—

TABLE 1.—*Continued*

Row No.	Depth, inches	Per cent	Per cent	Weighted average	Row No.	Depth, inches	Per cent	Per cent	Weighted average
Percentage moisture following rain (3 days after 1.83 inchs and 1 day after 0.1 inch)									
5	0–6	34.91	37.93		68	0–6	29.36	30.75	
	7–12	23.01	32.95			7–12	23.17	17.94	
	13–24	21.16	22.97			13–24	18.67	16.32	
	25–36	17.91	20.13	24.43		25–36	14.18	12.18	18.61
14	0–6	31.35	38.54		77	0–6	30.02	30.58	
	7–12	22.59	23.08			7–12	17.01	23.22	
	13–24	22.52	20.96			13–24	17.41	16.34	
	25–36	19.96	17.97	23.20		25–36	12.45	11.79	18.14
23	0–6	28.32	33.79		86	0–6	28.21	26.24	
	7–12	22.81	24.94			7–12	14.84	14.73	
	13–24	22.58	23.82			13–24	10.63	14.79	
	25–36	19.69	21.03	23.67		25–36	9.26	10.46	14.53
32	0–6	34.62	27.97		95	0–6	25.50	25.94	
	7–12	31.82	18.67			7–12	22.67	17.18	
	13–24	22.59	18.97			13–24	12.31	13.32	
	25–36	19.04	17.28	22.40		25–36	10.33	11.03	15.44
41	0–6	33.35	35.65		104	0–6	25.43	25.43	
	7–12	20.29	23.16			7–12	22.96	16.26	
	13–24	18.91	21.71			13–24	17.59	13.84	
	25–36	14.49	19.78	21.85		25–36	12.13	12.86	16.91
50	0–6	28.93	33.38		107	0–6	26.28	26.33	
	7–12	18.94	20.54			7–12	23.73	18.47	
	13–24	21.36	19.42			13–24	17.56	14.03	
	25–36	14.19	15.73	20.26		25–36	10.65	13.17	17.13
59	0–6	23.42	33.68			——	——	——	——
	7–12	18.45	24.24			——	——	——	——
	13–24	17.97	18.98			——	——	——	——
	25–36	13.20	13.89	18.99		——	——	——	——

0.1 inch. The determinations were made for the upper 6 inches of soil, the second 6 inches, the second foot, and the third foot. Weighted averages for the duplicate samples covering the 3-foot section are given. These show, in the one case, a more or less gradual decline in moisture from approximately 20% to about 10%, progressing from row 5 on the upper portion of the slope to row 107 on the lower portion. This trend for the dry period samples is followed closely by the determinations made following rain. In the latter case the decline extends from about 24% to approximately 16%. There is some irregularity in the data, but the trend is apparent.

The moisture determinations indicate the existence of a difference in water-holding capacity of the soil extending across the field. Accordingly, measurements of the relative water-holding capacity for

each of the rows were made. Two depth zones were arbitrarily chosen, *viz.*, 0–6 inches and 18–24 inches. Table 2 gives the percentage capacity for each row at the two different levels. At the 0–6 inch level there is a fairly regular decline from about 55% to approximately 46%, extending from row 5 to row 107. At the 18–24 inch level a similar decline is found ranging from about 36% to about 31% for the same rows. Clearly, the increasing amount of soil erosion is accompanied by changes in the water content and the relative water-holding capacity of the soil.

TABLE 2.—*Relative water-holding capacity of the area (Acre B2).*

Row No.	0–6 inch depth	18–24 inch depth	Row No.	0–6 inch depth	18–24 inch depth
	%	%		%	%
5	53.7	34.5	68	51.9	32.5
14	56.1	36.9	77	50.3	31.0
23	55.5	36.4	86	49.5	30.8
32	54.9	34.0	95	47.7	30.5
41	54.6	34.1	104	45.9	30.6
50	52.5	32.9	107	46.1	31.0
59	50.8	31.7	—	—	—

A physical study of soil samples obtained from each row and furnished through the courtesy of Dr. H. G. Byers of the U. S. Bureau of Chemistry and Soils provides additional evidence of the changes which have occurred in this soil. These data are given in Table 3. The colloid determined by the moisture absorption method shows a gradual decline across the field, dropping from about 58% on the upper portion to about 33% at the lower end of the acre. The moisture equivalent also declines in the same direction and is approximately parallel to the trend of relative water-holding capacity data and the soil moisture determinations shown above. The organic matter figures are more irregular, but a similar trend of decline is discernible and the data are in line with expectation as indicated by the soil profile.

The mechanical analysis is of interest. On the more highly eroded portion of the field the percentage of gravel, sand, and silt is higher than on the more nearly level, upper, less eroded portion. The clay, on the other hand, gradually decreases in amount as the degree of erosion becomes more pronounced. It appears that the clay and the colloid material, representing the lighter portions of the soil complex, have disappeared more rapidly during the eroding process than have the heavier soil particles.

With the increase in loss of organic matter, clay, and colloids, as erosion progresses, the impaired moisture relationships are but to be expected. Cotton production in this belt is largely dependent on

TABLE 3.—*Physical study of soil samples from the area (Acre B2).**

Row No.	Colloid by moisture absorption method	Moisture equivalent	Organic matter	Mechanical analysis									
				Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Total	Solution loss	Colloid 0.002–0.0
	%	%	%	%	%	%	%	%	%	%	%	%	%
5	57.3	37.9	3.72	0.3	0.9	1.2	3.4	3.4	24.5	65.8	100.0	0.6	55.6
14	58.7	37.1	3.15	0.4	0.7	1.0	3.3	3.2	24.2	67.2	100.0	0.5	56.2
23	58.5	37.9	3.35	0.4	0.7	1.0	3.2	3.0	25.4	66.2	99.9	0.9	55.9
32	57.0	37.2	3.21	0.3	0.7	1.1	3.2	3.4	24.6	66.6	99.9	1.0	55.1
41	56.1	36.6	3.12	0.3	0.5	1.1	3.6	3.3	24.6	65.5	99.9	0.6	54.0
50	47.6	34.4	3.09	0.4	0.7	1.0	3.5	3.6	24.7	66.0	99.9	1.0	54.4
59	46.9	32.1	3.15	0.3	0.7	1.0	3.8	4.0	25.2	65.0	100.0	1.2	50.4
68	46.2	30.9	1.89	0.5	0.7	1.0	4.4	4.5	24.4	64.4	99.9	1.4	49.7
77	41.3	30.9	2.12	0.7	1.1	1.1	4.6	4.4	27.9	60.2	100.0	1.1	43.8
86	39.2	28.4	1.76	1.2	1.4	1.4	5.5	5.0	28.1	57.4	100.0	1.2	41.5
95	36.0	26.0	1.58	1.1	1.5	1.5	5.8	5.6	28.6	56.1	100.1	0.9	39.2
104	32.2	26.1	2.35	1.0	1.7	1.7	6.0	5.8	28.2	55.5	99.9	0.8	38.6
107	33.3	26.4	2.46	1.2	1.6	1.5	5.4	6.1	28.0	56.3	100.1	1.1	38.8

*These data supplied through the courtesy of Dr. H. G. Byers, Chief Division of Soil Chemistry and Physics, U. S. Bureau of Chemistry and Soils.

soil moisture accumulated during the fall, winter, and spring; since but a small part of the annual precipitation occurs during the summer months. The storage of soil moisture is therefore an important matter in this region and the common expression of planters with reference to a good supply of moisture that "there is a good season in the ground" has a very definite meaning. At least one of the important reasons for the decline in cotton yields following soil erosion is that of impaired soil moisture relations. The possibility of improving such eroded lands through the incorporation of organic matter is one which should not be overlooked. Preliminary work in this direction has already indicated much of promise.

CONCLUSIONS

The practice of continuously growing cotton in the black belt of Texas is often followed by soil erosion, which, in turn, is accompanied by decreased yields. Observations indicate that even a relatively slight degree of erosion has a marked effect upon the yield. A study of a specific case has been made, using an area having a slight slope and a relatively slight degree of erosion extending in one direction across its surface. The soil profile has been measured and shows the loss of surface soil which has occurred in increasing amount down the 1% slope.

Cotton yields as measured by check rows located every third row showed a definite downward trend as erosion progressed. Soil moisture determinations and measurements of the relative water-holding capacity of the soil likewise showed a downward trend. A physical study of the soil across the area indicated the following: Loss of organic matter, decline in amount of colloids, decline in moisture equivalent, and lower percentage of clay on the eroded than on the uneroded portions of the slope.

AN EXTENSION PROGRAM FOR THE CONTROL OF SOIL EROSION IN NEBRASKA[1]

P. H. STEWART[2]

Due to the fact that Nebraska lies in a transition zone with a wide variation from east to west in rainfall, soil areas, and types of farming, the problem of soil washing is present in most of its many forms and intensities.

The problem has been considered from three angles, i. e., the loss of organic matter, the loss of precipitation as runoff, and the formation of value-reducing, machinery-breaking, time-wasting gullies. The exposure of the subsoil by sheet erosion has been considered as a part of the first phase.

THE ORGANIC MATTER PHASE

It is a fairly common remark among Nebraska farmers that plows pull heavier today than they did 30 to 40 years ago when the soil of the state was new. The complaint is that from one to two more horses are needed now on a certain size of plow compared to years ago. Studies by agronomists at the Nebraska Agricultural College show a distinct loss of organic matter in the cultivated soils of the state.[3] We cannot expect to maintain the organic matter in cultivated soils at the height common to virgin soils, but it must be kept above a certain point if crop yields are not to be reduced. It is commonly believed that a reasonable amount of organic matter in the soil is necessary for proper tilth, water absorption, and the production of nitrates. It is the main object of agronomy extension workers in Nebraska to promote cropping systems which will maintain the soil organic matter at a reasonable height. This is believed to be the most fundamental phase of erosion control under Nebraska conditions. This involves legumes and livestock to a very important degree.

SOIL MOISTURE CONDITIONS

It may truly be said that soil moisture is usually the limiting factor in crop production in Nebraska. The same statement will

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as Paper No. 105, Journal Series. Also, presented as part of a symposium on the "Control of Soil Erosion" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Extension Agronomist.

[3]RUSSEL, J. C. Organic matter problems under dry farming conditions. Jour. Amer. Soc. Agron., 21: 960–967. 1929.

hold for much of the corn belt, as demonstrated with a vengeance during the past season. The annual precipitation decreases from some 33 inches in southeastern Nebraska to 16 inches in the western part of the state. Drought and hot winds are usually a menace in certain sections each year. The conservation of precipitation and particularly the prevention of runoff is therefore a matter of great importance. Work by Duley and Miller[4] has shown the importance of sod and legume crops in preventing runoff and the loss of surface soil. The facts demonstrated in this erosion study are fundamental in the development of Nebraska's soil saving program.

GULLY FORMATION

The damage to land from gullies is so well recognized that it needs little discussion. It is an obvious problem in erosion control and catches the eye of even the casual observer. Yet, by and large, the total loss caused by gullies is not as great as that caused by the less apparent sheet erosion and the loss of needed precipitation which escapes as runoff. However, it is not difficult to find some farms which have been lowered 50% or more in value due to gully erosion brought on usually by a tenant regime of grain farming.

SOIL AREAS OF NEBRASKA

It is estimated that some 24,250 of the 77,510 square miles in Nebraska are affected by soil erosion. The most serious damage is done in the drift hill area, a region of 6,700 square miles in southeast Nebraska. The relatively heavier rainfall in this section of the state and the tendency of this glacial soil to erode are factors influencing erosion. The loess hill area, composing some 11,900 square miles in northeast and northcentral Nebraska and along the southern border of the state, is also a region where erosion is an important problem.

The rough loess canyon lands making up 1,500 square miles of rolling to rough areas are affected by erosion to an appreciable extent if under cultivation. The 5,900 square miles of bottom and terrace soils may be injured at least for the current year by having crops buried under deposits from eroded uplands. In the end, such lands probably gain rather than lose by having the top soil of uplands deposited on them. The High Plains area is occasionally eroded by dashing rains but here the problem is more one of water conservation. Erosion is not a problem in the sand hills and in the loess plains area.

[4]Duley, F. L., and Miller, M. F. Erosion and surface runoff under different soil conditions. Mo. Agr. Exp. Sta. Res. Bul. 63. 1923.

THE NEBRASKA EXTENSION PROGRAM

Altho some preliminary work was carried on in 1917, organized work in erosion control was not started until 1921. At that time a project in cooperation with the Department of Agricultural Engineering was drawn up. This relationship still exists. The Extension Agricultural Engineers are responsible for engineering phases of erosion work, while the Extension Agronomists are responsible for rotation, cultural practice, management, and soil maintenance phases. This does not mean that the engineers do not talk crops and soils or the agronomists talk terraces, soil saving, and brush dams. The entire subject of erosion control is discussed at such meetings and demonstrations as may be attended by the specialists in either line. Pictures, data, and subject matter are exchanged between agronomy and engineering specialists so that the workers in both lines are in agreement on policies and practices. An extension bulletin on soil washing was prepared by specialists in the two lines of work. Judging by experience, this close relationship between extension specialists whose work overlaps is fundamental to success. There is too little rather than too much inter-departmental cooperation of this type.

METHODS OF ATTACK

Certain phases of erosion control work have been concentrated in particular areas or counties. It is felt that this is necessary in conducting a long-time project such as this. A 5-year plan is laid out for certain counties with detailed steps for each year. In other areas erosion control work has not been made a major project yet a certain amount of work is done especially through legume acreage campaigns, the corn yield contest, and by other related phases of work which are state-wide in scope. The following methods are among the most important ones used in carrying on the erosion control work.

Circular letters.—A series of three or four letters have been used in some 20 counties of the state. These letters are of a brief nature carrying a picture at the top to attract attention. They are of an interest-arousing, sales talk, sign on the dotted line type, common in commercial lines. They have proved very satisfactory. The last letter in the series has carried a card to be returned for special bulletins or on which a request for a demonstration or for specific information may be made.

Meetings.—Many schoolhouse and other local meetings have been held in the counties conducting intensified work. Both agronomy and agricultural engineering specialists have assisted county agents in conducting these meetings. The most satisfactory plan of procedure

seems to be to discuss soil erosion then clinch the main points by using carefully prepared and selected slides. Often local cooperators for certain phases, such as brush dams, soil-saving dams, terraces, and rotation demonstrations, can be arranged for at these meetings. Often times the day can be spent planning and installing result demonstrations with evening meetings to complete the day's work.

Soil robber trials.—Soil robber trials have proved very effective in creating an interest in soil erosion problems. A complete circular giving all of the details for a trial has been prepared and used before thousands of Nebraska people. It has been used very effectively at banquets. It can often be put on by community clubs and other local organizations where it offers much information in a "sugar-coated pill" form.

Soil service meetings.—In counties where soil surveys have become recently available these can often be used as a basis for rotation and soil management meetings using the map as an attention getter and taking up local cropping problems as determined by certain soil types. Result demonstrations often develop from such meetings. These are open meetings held during the winter months, scheduling two a day, one in the afternoon and one in the evening.

Corn yield contest.—It has been stated that from an agronomic standpoint the erosion problem of Nebraska is largely one of organic matter maintenance. Because of this fact, the Nebraska 10-acre corn yield contest has been of outstanding value in putting the value of legumes before the public. It has supplied illustration after illustration of the effect of legumes on crop yields and net returns, and thus has been of great value in publicity and in meetings. Winners in the contest have invariably had well-maintained and rotated fields, recently broken out of legume crops.

In 1928, samples of the upper 6 inches of soil were taken from 21 eastern Nebraska corn fields, 15 of these being from contest fields, while 6 were from soils of the same type on adjoining farms which had been reduced in fertility by an excess of grain farming. A summary of the organic matter content of the 15 contest fields showed an average of 4.10% organic matter in comparison with 3.39% organic matter in the poor soils. The corn yields averaged 83 bushels on the good fields and 25 bushels on the poor. An increase of 22% of organic matter in the good soils over the poor ones was associated with a 58-bushel increase in the yield of corn.

The results from the use of legumes by contestants in the 10-acre yield contest have been of great value in talking more legumes. It is believed that the more legume work has had something to do with

increasing the acreage of sweet clover in Nebraska from 30,000 acres in 1920 to 1,124,434 acres in 1930. Many eastern Nebraska farmers now seed sweet clover or some other legume with every acre of small grain.

County corn yield contests increase the interest in legumes. County corn days, or corn and hog days, as they are called in Nebraska, are one-day county-wide meetings at which time the results from the corn yield contest and the pig crop contest are discussed. Here again, the value of legumes in maintaining fertility and in preventing erosion and run-off may be emphasized.

Detailed surveys.—It has been found desirable in some cases to make a farm to farm survey of certain townships in order to get definite figures on legume crops, gullying, livestock, and similar facts having a relationship to soil maintenance and erosion prevention. Such data are often startling and they are always valuable to the worker who wants a measuring stick of results and sound information for a guide post. Judgment must be used in selecting areas and in deciding on the amount of such work to do.

Definite result demonstrations.—A certain number of result demonstrations are necessary and very important. Some phases of work adapt themselves to and require result demonstration more than others. Five main types of result demonstrations have been carried on in Nebraska in connection with the erosion work.

1. Cultural practices. In the more legume program an important problem has been to secure hardy alfalfa seed. Many farmers have been of the opinion that all alfalfa seed is similar in behavior. Result demonstrations have been established in practically all counties to demonstrate the difference in the hardiness of alfalfa from different sources and of different varieties. Seeding practices, liming, and inoculation were demonstrated in areas where there was difficulty in securing stands of legumes, although this condition is not prevalent in the state.

2. Rotation practices. In a few cases badly eroded farms have been taken over as demonstrations. Usually such farms had been rented and grain farmed. Legumes are worked into the rotation, with provision made for the utilization of pasture and forage by livestock. Some of these farms have been very valuable object lessons in land reclamation and management.

3. Brush dams. Many demonstrations of the proper way to install brush dams have been carried out. To begin with, it was necessary to determine how to build brush dams in order to secure the best results. Many meetings and demonstration have been held in areas where erosion is serious.

4. Soil-saving dams. Emergency measures are sometimes necessary in order to bring under control gullies which have been neglected. Sometimes whole farmsteads are threatened by deep gullies working back across fields. While the cost of soil-saving dams is high, they are sometimes necessary and where correctly installed they have been very successful in stopping large gullies. Many of these have been installed on public highways as culverts, to the distinct advantage of adjoining land owners.

5. Terracing. The status of terracing in Nebraska from both a soil-saving and moisture-saving standpoint is not yet clearly determined. There is still some question as to the practicability and need of terraces under Nebraska conditions. There are in Nebraska at the present time some 50 demonstrations. From the viewpoint of saving soil it is believed that terracing is a matter of last resort. Legumes and strip and contour farming are suggested with terracing to be used only when it seems necessary. Although some terracing demonstrations have been in operation in the state for eight seasons, they have not proved themselves so effective that the practice has spread to any appreciable extent to neighboring farms. Terracing, from the standpoint of moisture conservation, is being tried to a limited extent, but it is still more or less of an experiment. A number of cooperators are very enthusiastic about terracing from a moisture-saving viewpoint.

SUMMARY

1. Extension programs to control erosion have been cooperative projects between specialists in agronomy and agricultural engineering.

2. Soil erosion is an important problem in Nebraska from the standpoint of organic matter losses, soil tilth and texture, the loss of runoff, and damage to land and land values by gullies and ditches.

3. The loss of organic matter through the removal of the surface soil by sheet erosion is the most important damage to Nebraska land by soil washing, although other losses are important.

4. The use of legume crops to maintain the organic matter content of the soil is emphasized for Nebraska conditions.

5. The most important methods used in carrying on the erosion control programs include circular letters, schoolhouse meetings, publicity, soil robber trials, soil service meetings, corn yield contests, detailed surveys of definite areas, and result demonstrations of definite practices, such as installing brush and soil-saving dams, terracing, and carrying out definite rotation practices.

THE PODSOLIC PROCESS IN SOILS[1]

T. J. DUNNEWALD[2]

Timbered soils become leached and gray colored in time due to the solution effects of rain water combined with soluble products of organic matter deposited on top of the ground by the trees. Basic materials, such as iron, manganese, and alumina, are removed from the top soil (gray A layer) and accumulated in the subsurface or B layer. Colloidal clay and organic matter also may accumulate in the B horizon and form hard compact layers. Analyses also show that silica accumulates as a residual product in the top layer. This process is called podsolization.[3]

The podsolic process has been reproduced in the laboratory by covering a black, acid, prairie soil with oak leaves and leaching the whole with distilled water. The filtrate from the oak leaf covered soil contained more silica, iron, alumina, manganese, and phosphorous than the filtrate from the soil without the oak leaves. Less calcium, magnesium, and sulfur were found in the former.

The present paper attempts to follow some of the details of the podsolic process. Two sets of soil samples had been previously obtained in a mountain area where the black grass soil broke sharply into gray, podsolic, timbered soil. Each set of samples consisted of four horizons from the dark grass soil and four from the nearby gray timbered soil.

An extract of pine needles from the timbered area was prepared by bringing to a boil 25 grams of needles with 500 cc of distilled water. The liquid was then filtered hot with suction through a Buchner funnel. This extract was found to have the following composition:

Organic matter	1.38%	Silica	.07%
Humus	0.41%	Iron and alumina	.06%
Organic phosphorus	126 ppm	Calcium and magnesium	.095%
Reaction (pH)	5.9	Mineral phosphorus	38 ppm

A weighed portion of air-dry soil (horizon A_0) was brought to a boil with the 500 cc of pine needle extract and filtered as above. A portion of this extract was reserved for analysis and the rest again brought to a boil with a proportionate amount of soil from horizon A.

[1]Contribution from the Department of Soils, Wyoming College of Agriculture, Laramie, Wyo. Published with the approval of the Dean. Received for publication November 25, 1930.

[2]Assistant in Soil Investigations.

[3]GLINKA. The Great Soil Groups of the World and their Development. (Page 87.)

This process was continued with all four horizons of each soil, the proportion of soil to extract being the same throughout. This process was designed to simulate the passage of rain water through the litter and then through successive horizons of the soil beneath the trees.

The extracts, after boiling, were placed in clean pyrex flasks and tightly corked with rubber stoppers. A bacterial or fungous growth appeared on only one of the entire set after standing 30 days, indicating complete sterilization. A colorimetric determination of the reaction of the solutions was made 5 days after the extracts were completed and again 30 days later by the same method (Table 1). The results indicate that in contact with the A_0 and A_1 horizons of soil, the pine needle extract tended to become more alkaline, but when it reached the lower horizons it returned to its normal reaction in three of the four soils. The result of the second determination after 30 days seems to show that all the extracts became more alkaline and stabilized at about pH 7.1 to 7.5. No explanation for the behavior of these extracts is offered.

TABLE 1.—*Reactions of the soils and their extracts after 5 and after 35 days, respectively.*

	Dark acid grass soil				Gray acid timbered soil			
Profile	A_0	A_1	B	C	A_0	A_1	B	C
Soil No.	10	11	12	13	6	7	8	9
Soil reaction	6.2	6.1	7.3	7.0	6.5	6.0	6.0	5.9
Needle extract, Feb. 1	6.8	7.0	6.9	7.5	7.1	6.7	5.9	5.9
Needle extract, Feb. 29	7.1	7.1	7.1	7.1	6.9	7.3	7.1	7.3

	Dark acid grass soil				Gray acid timbered soil				Pine needle extract
Profile	A_0	A_1	B	C	A_1	A_1	B	C	
Soil No.	117	118	119	120	122	123	124	125	
Soil reaction	6.0	6.0	6.1	6.1	5.8	6.0	6.0	5.8	5.9
Needle extract, Feb. 1	6.7	6.2	5.9	5.6	6.5	6.3	5.9	5.8	5.9
Needle extract, Feb. 29	7.5	7.3	7.5	7.1	7.3	7.1	6.9	6.9	7.2

In general, the first contact of pine needle extract with the A_0 and A_1 horizons of the acid soils resulted in increased alkalinity of the solution, while the lower two horizons caused the solution to return to normal or slightly greater acidity than originally found. Both the black and podsolic soils reacted alike in this respect. Apparently basic material was absorbed by the extract from the A_0 and A_1 horizons and this was neutralized or removed in the B horizon.

SOLUBLE SILICA

Analyses of the extracts for SiO_2 indicate that the podsolic timbered soils gave up more silica to the extracts than did the grass soils. This might be true because more silica is present or because the silica of the podsol soil is more soluble. One would not expect the latter to be true, since these soils had already been leached. In the first set, the silica content increased in the B and C horizons, but in the second set the content decreased in the B horizon. The parent (C horizon) of the podsol soils greatly increased the silica content of the extract, while that beneath the grass soils only increased the silica slightly or not at all. The SiO_2 content of the extracts is shown in Table 2.

TABLE 2.—*Silica content of extracts of acid grass and timbered soils.*

	Acid grass soil				Acid timbered soil			
Profile	A_0	A_1	B	C	A_0	A_1	B	C
Horizon No.	10	11	12	13	6	7	8	9
Silica in extract from soil, %...	0.105	0.18	0.20	0.25	0.19	0.22	0.28	0.91

	Acid grass soil				Acid timbered soil			
Profile	A_0	A_1	B	C	A_0	A_1	B	C
Horizon No.	117	118	119	120	122	123	124	125
Silica in extract from soil, %...	0.055	0.050	0.040	0.045	0.06	0.06	0.045	0.085

It is not clear from these data just why or how silica is accumulated in the surface horizons of podsolic timbered soils.

THE SESQUI-OXIDES (IRON, ALUMINA, MANGANESE)

The extracts were also analyzed for iron, alumina, and manganese. The results show that the pine needle extract, containing 0.06% of iron and alumina, absorbs more iron and alumina in its first contact with every soil. This increased mineral content picked up in the surface horizon is again extracted in the lower (A_1 and B) horizons. The rate of extraction in the subsoils varies and in the first set the increased iron-alumina content reappears in the parent material (C) horizon but does not do so in the second set. In the second set the extract is poorer in iron and alumina after contact with the parent material than when it entered the soil. It is much richer after contact with the parent material beneath set No. 1. The podsolic process of removal of iron and alumina from the top soil and redeposit in lower horizons is well shown in three of the soils but does not appear in the first dark grass soil (Table 3).

TABLE 3.—*Oxides of iron and alumina in extracts of acid grass and timbered soils.*

	Set No. 1							
	Dark grass soil No.				Timbered soil No.			
	10	11	12	13	6	7	8	9
Fe and Al in soil extract, %	0.105	0.110	0.105	0.160	0.080	0.055	0.080	0.110

	Set No. 2							
	Dark grass soil No.				Timbered soil No.			
	117	118	119	120	122	123	124	125
Fe and Al in soil extract, %	0.090	0.045	0.055	0.045	0.110	0.085	0.080	0.060

Reference to Table 1 shows that this latter soil is basic in the B and C horizons. The extraction of iron and alumina from the solution does not occur in the basic horizons of this soil as it does in the more acid horizons of the other soils. Acidity appears therefore as a necessary preliminary for the concentration of iron and alumina in the lower horizons of soil.

CALCIUM AND MAGNESIUM

Analysis of the extracts for calcium and magnesium shows that roughly twice as much of these basic materials is carried away from the soil horizons as of the sesqui-oxides, and this despite the fact that the soils themselves contain many times as much iron and alumina as they do of calcium and magnesium.

Second, there is little or no tendency in any of the soils for the calcium and magnesium extracted from the surface layer to be reabsorbed by lower horizons. The removal of bases is therefore much more rapid than that of sesqui-oxides, which explains why podsolic soils tend to become more and more acid.

Table 4 gives the analyses for bases and sesqui-oxides of the soils and of the pine needle extracts of these same soils.

While from 1 to 4% of the iron and alumina were being absorbed from the soils by the pine needle extract, from 20 to 90% of the calcium and magnesium were being extracted under the same conditions.

This relation was uniform for both grass and timber soils in the case of the sesqui-oxides. In the case of the bases, the removal was from two to four times as rapid from the gray timbered soils as from the corresponding dark grass soils.

The dark grass soils, therefore, exhibit an ability to resist the loss of basic material as compared to the gray timbered soils. It is probable

TABLE 4.—*Bases and sesqui-oxides of soils and soil extracts.*

	Soil No.	Fe and Al oxides in soil, %	Ca and Mg oxides in soil, %	Fe and Al oxides in extracts, %	Ca and Mg oxides in extracts, %
		Set No. 1			
Grass soils........	10	2.41	1.05	0.105	0.230
	11	2.45	0.61	0.110	0.210
	12	3.02	0.79	.0105	0.190
	13	3.93	1.00	0.160	0.200
Timbered soils.....	6	5.85	0.16	0.080	0.130
	7	3.30	0.00	0.055	0.140
	8	2.48	0.00	0.080	0.170
	9	0.68	0.17	0.110	0.150
		Set No. 2			
Grass soils........	117	4.04	2.16	0.090	0.105
	118	5.96	0.68	0.045	0.090
	119	7.72	0.39	0.055	0.095
	120	7.90	0.22	0.045	0.075
Timbered soils.....	122	5.69	0.56	0.110	0.200
	123	4.44	0.19	0.085	0.165
	124	8.31	0.42	0.080	0.145
	125	8.39	0.19	0.060	0.145

that the development of grass vegetation and accumulation of organic matter of the prairie soils occurs under basic or neutral soil conditions in the presence of calcium and magnesium. The slowing down of base removal from the grass soils preserves their stability until slow development of acidity and base removal makes conditions unfavorable for the grasses and trees are then able to invade the soil. The deposit of organic matter on top of the soil by the trees hastens the further removal of bases and development of greater acidity in the soil.

AVAILABLE PHOSPHORUS

A previous paper[4] shows that phosphorus availability decreases with increase of rainfall and that gray podsolic soils of the mountains show smaller amounts of available phosphorus than adjoining prairie grass soils do. Table 5 gives the available phosphorus (by modified Denige method) in ppm of the soils and the extracts which have been previously discussed.

The pine needle extract which originally contained 38 ppm of mineral phosphorus and 126 ppm organic phosphorus in available form is immediately reduced to 19, 17, 34, and 23 ppm, respectively, upon contact with the four soils. Not only is the phosphorus content of the timbered soils lower than that of the grass soils, but ab-

[4]Jour. Amer. Soc. Agron., 21: 934–936. 1929.

TABLE 5.—*Available phosphorus in podsol and grass soils and their extracts.*

	Soil No.	Available phosphorus in the soils, ppm		Available phosphorus in the extracts, ppm	
		Organic	Total	Organic	Total
		Set No. 1			
Grass soil..........	10	20	50	12.5	19.0
	11	11	39	9.5	15.5
	12	7	32	11.0	18.0
	13	5	25	14.0	20.5
Timbered soil......	6	2	37	12.0	17.0
	7	11	47	6.5	11.0
	8	11	25	13.5	17.0
	9	10	20	13.0	17.0
		Set No. 2			
Grass soil..........	117	39	84	16.0	34.0
	118	12	27	12.0	22.0
	119	2	27	12.0	20.0
	120	4	32	8.0	16.0
Timbered soil......	122	32	40	5.0	23.0
	123	16	31	11.5	20.5
	124	12	22	6.0	15.5
	125	12	17	6.0	11.0

sorption of phosphorus from the needle extract is greatest in the timbered soils. The available phosphorus content of the extract decreases as it penetrates the subsoil horizons in every case, and generally approaches the content of the soil horizon with which it is in contact.

The extracts, after contact with the parent material beneath the grass soils, still contain 20 ppm and 16 ppm of phosphorus as compared to 17 ppm and 11 ppm beneath the timbered soils which may indicate a more rapid loss of phosphorus from grass soil than from podsolic timber soils.

SUMMARY

The method used failed to show that organic matter leaching explains the accumulation of silica in the surface horizons of podsolic soils. The removal of iron and alumina from the surface horizons and their re-absorption in the subsoil are shown in the acid horizons of three of the soils used. The rapid removal of bases from timbered soil as compared to grass soil is shown and the slower removal of sesqui-oxide as compared to the rapid removal of bases is brought out. Available phosphorus seems to be lost more rapidly into the subsoil of grass soils than is the case with timbered soils.

If this method parallels natural processes, it is necessary to conclude that organic matter is not concerned in the podsolic accumulation of

silica but is concerned in the translocation of bases and sesqui-oxides. Extraction of the bases and formation of acid conditions appear to be a necessary preliminary to the deposition of iron and alumina in the subsoil. The bases are removed from the surface soil about 20 times as fast as the sesqui-oxides under the same conditions.

INTERPRETATION AND POPULAR PRESENTATION OF DATA SHOWING THE ECONOMIC RESULTS OF FERTILIZATION[1]

H. W. Warner[2]

In any discussion of the economics of fertilization or any other soil-improving practice, it is correct to assume that there is but one sound justification for the farmer's adoption of such practices, and that is profit. This is best proved by the fact that the only practices that have persisted and had wide-spread acceptance by the farmer are those that have resulted profitably to him.

In the past we have heard other reasons given for soil improvement such as "keep good soil good," "leave the land as good as we found it," "preserve the fertility for posterity," and others. These are commendable reasons for putting money and labor into soil fertility, but, unless the practices recommended to accomplish these more idealistic results pay their way and leave a profit for the farmer, wide adoption will not follow.

Even those who follow good soil fertility practices for the expressed purposes of "leaving the land as good as we found it," or "looking out for posterity," really do so for profit either in the form of personal satisfaction or by way of profit to those who shall later inherit or buy the land. Under the highly competitive conditions of farming during the past ten years and at present, probably few farmers and practically no agricultural scientists will advocate the use of fertilizer, or any other soil treatment, unless there is an affirmative answer to the question, "Does it pay?"

Data from fertility experiments and reliable field tests and demonstrations in perhaps 30 fertilizer-using states will show a crop return of $2 to $5 (in some cases much higher) per $1 spent for fertilizer. The most common rates of return are from $2.50 to $4 for $1 invested. That similar returns are actually realized under farm conditions is indicated by the experiences of some 48,000 farmers, as given in the survey made by The National Fertilizer Association, which indicate that they obtain crop increases valued at $3.54 per $1 worth of fertilizer.

From an investment standpoint, fertilization should return to the farmer the money spent for the treatment, pay for the extra labor of making the treatment and producing the crop increase, and allow for the element of risk, plus a fair profit.

[1]Contribution from the Technical Department, The Barrett Company, New York City. Presented at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Agronomist.

The only indefinite item, therefore, is the element of risk which, while it exists in varying degrees for all crops and conditions, is believed to be not greater than 1 in 10 as an average. That is, approved and recommended fertilizer treatments will return more than their cost in at least 9 out of 10 cases. This is considered conservative but will serve for this illustration.

Then, per dollar's worth of fertilizer, the farmer expects and should have a minimum return to cover the following cost items:

Fertilizer, including estimated cost to apply	$1.10
Risk element (estimated at 10%)	.11
Interest on investment @ 8%	.09
Cost to harvest crop increase, estimated	.20
Total	$1.50

Presumably any amount returned over $1.50 is profit on the investment or pay for managerial ability. Hence, it would seem that average returns of $2 for $1 would be very attractive to the farmer, and that returns of $3 or more for $1 would result in a very rapid increase in the use of fertilizer. That this has not happened, beyond a gradual average rate of increase, is shown by fertilizer tonnage records.

It appears, then, that the farmer requires a very much higher rate of return from his fertilizer investment than from investments in feeds, seeds, machinery, or mechanical power; or that he has not properly interpreted fertilizer crop returns into economic benefits. No doubt both are factors. The writer is of the opinion that few farmers fully and clearly see the economic benefits of fertilization; also, that interpretations and presentations of the economic results of fertilization can frequently be made more significant and interesting and, therefore, more effective in influencing farmers to adopt approved fertilizer practices.

The following illustrates different ways of interpreting the results of a fertilizer experiment having the following assumed set of data: One acre of corn receiving 1 unit of fertilizer yields 40 bushels of corn at a total production cost of $22; with an additional unit of fertilizer the yield is 50 bushels at a total cost of $24 per acre. Making no allowance for differences in quality, the crop in both cases is valued at 60 cents per bushel, ready to harvest.

The simple equations for the two cases then become:

40 bushels @ $.60 = $24.00 minus $22.00 = $2 profit per acre
50 bushels @ .60 = 30.00 minus 24.00 = 6 profit per acre

The profit from the added unit of fertilizer is, therefore, $6.00 minus $2.00, or $4.00 per acre.

To make the illustration a little more pointed it can be shown that at the additional cost of $2.00 the net profit is trebled. Or, if you wish to make a more striking comparison, you can say that at an added cost of less than 10% the net profit is increased 200%.

Using the same data the economic results may also be interpreted into terms of unit cost of production, as follows:

40 bushels cost $22, or $.55 each, at a profit of $.05 per bushel
50 bushels cost 24, or .48 each, at a profit of .12 per bushel

This will appeal to cost-of-production-minded persons but will not have a strong appeal to farmers generally unless followed by a further comparison, as follows:

40 bushels @ $.05 profit, makes $2.00 total acre profit
50 bushels @ .12 profit, makes 6.00 total acre profit

Either interpretation is correct, but of different educational value.

Still a third way of interpreting the same data is as follows:

40 bushels cost $22, or $.55 each, at a profit of $.05 each
10 bushels (increase) cost $2, or $.20 each, at a profit of $.40 each

In other words, regardless of the cost of the first 40 bushels, the extra 10 bushels cost only 20 cents each. This illustrates how fertilizer enables the farmer to produce "a few cheap bushels," or bales, or tons, as may be the case.

This interpretation may draw some criticism on the ground that all the crop units produced should share equally in all items of cost. The fact remains, however, that the extra 10 bushels are the direct result of a specific treatment at a cost of $2 and may properly be credited to the treatment. This is one of the most effective ways of interpreting fertilizer results into terms of easily-understood, useful farm economics.

Such results may be given a further interpretation into terms of field or farm profits, as has been effectively done by extension workers in Missouri and, no doubt, elsewhere. The interpretation is that assuming the farmer wants a net profit of $300 on his corn crop, he may choose one of the two courses following:

$300 profit derived from 150 acres @ $2 profit per acre, or
$300 profit derived from 50 acres @ $6 profit per acre

This, it seems, is more effective than to make the usual comparison:

50 acres @ $2 profit equals $100 profit
50 acres @ $6 profit equals $300 profit

In recent years, soil-improving practices have been considered largely from the standpoint of their effect on unit production costs. This is sound economics, of course, but have we not sometimes over-

looked the fact that in the final accounting *total net profit* is the thing that counts? Unit cost and unit profit are very important factors and usually, but not always, govern total net profit.

The exceptions to the general rule make an interesting phase of fertilizer economics which may be expressed in the question, "Is fertilization profitable to the farmer only when it reduces the unit cost of production?"

When this question was presented to a farm management authority who has made some valuable studies in fertilizer economics, he admitted, that until the point was illustrated, it had not occurred to him that fertilization was ever justifiable if it increased unit cost. It is doubtful if many farmers would agree that fertilizer should be used in any case where it increases rather than decreases the unit cost of a crop.

But there are cases which illustrate that it is not always necessary for fertilization to reduce unit costs in order to be profitable. The U. S. Dept. of Agriculture has reported the average results of six potato fertilizer experiments on as many soil types, as follows: Without fertilizer, 149 bushels; with fertilizer, 230 bushels; increase, 81 bushels. Taking $80 per acre as the cost of production without fertilizer, $25 as the per acre cost of the fertilizer, and 75 cents a bushel as the value of the crop, ready to harvest, we have these equations:

$ 80 ÷ 149 equals $.537 (cost per bushel) at a profit of $.213 each, or $31.75 per acre

$105 ÷ 230 equals $.456 (cost per bushel) at a profit of $.294 each, or $67.50 per acre

But suppose it had required $50 worth of fertilizer, instead of $25 worth, to produce the 81-bushel increase, would it still have been economically justifiable? Here are the equations:

$ 80 ÷ 149 equals $.537 (cost per bushel) at a profit of $.213 each, or $31.75 per acre

$130 ÷ 230 equals $.565 (cost per bushel) at a profit of $.185 each, or $42.50 per acre

Note that the acre profit was greater even though the unit cost was increased, due of course to the much larger number of units.

This relation operates within rather narrow limits depending on the spread between the value of the crop and the cost of producing it. In the illustration above, if potatoes were figured at 85 cents or $1.00 a bushel, the unit cost might be increased several cents more and still show increased acre profits.

The following is another case arising from the results of pasture fertilizer demonstrations on 103 farms in 1929, and reported by The National Fertilizer Association:

Treatments	None	0-10-0	Lime and 0-10-0	Lime and 0-10-10	Lime and 5-10-10
Annual cost per acre	$1.80	$4.21	$6.41	$8.49	$17.16
Average yield crude protein, lbs.	177	235	266	344	488
Cost per 100 lbs. crude protein	$1.02	$1.79	$2.41	$2.46	$3.52
*Value per acre of crude protein	22.13	28.38	33.25	43.00	61.00
Gain over cost per acre	20.33	24.17	26.84	34.51	43.84

*Basis of $12.50 per 100 pounds crude protein in 20% dairy feed.

Note that the cost per 100 pounds of crude protein increases with each successive fertilizer treatment until it reaches $3.52 per cwt. compared to $1.02 on the untreated land. The true economy is shown only when the total value of the crude protein per acre is compared with the cost of producing each acre. (See last line of figures.)

These cases will serve to show that, while good soil practices usually reduce the unit cost of production, they may still be profitable in certain cases, even though the unit cost be increased.

A QUARTER CENTURY OF DRY-FARM EXPERIMENTS AT NEPHI, UTAH[1]

A. F. BRACKEN AND GEORGE STEWART[2]

Utah is naturally an arid state with precipitation varying from 3.71 inches at Wendover, located in the vast desert region on the western border, to more than 40 inches on some of the mountain ranges. Desert and mountain areas and other untillable land combined total about 95% of Utah's land area. The remaining 5% constitutes all of the land which will yield to cultivation either by irrigation or by dry farming.

Dry farming, the particular type of agriculture here considered, began in Utah, in Boxelder County, about 1863, and has gradually spread to all parts of the state wherever rainfall is sufficient and where topography, soil, and transportation permit.

During the 76 years that dry farming has been practiced in Utah, many changes in tillage practices, cropping systems, crops, and crop varieties have taken place in keeping with experience and experimental evidence. This progressive improvement has now resulted in a nearly complete standardization of crops and cropping methods.

EXPERIMENTAL DATA

The experimental work of the Nephi Dry-farm Sub-station reported in this paper consists of the following main projects: (1) Tillage tests, (2) seeding experiments, (3) cropping systems, (4) fertility studies, and (5) rotation experiments.

TILLAGE EXPERIMENTS

Treatment of land before plowing.—After harvesting a crop of wheat, often for some particular reason farmers deviate from the general practice of normal fall or spring plowing of the stubble land. In 1916, experiments were begun which include (1) disking of the wheat land immediately after harvest followed by either fall or spring plowing, (2) burning all or part of the straw left by the combine harvester and thresher, and (3) leaving all or part of the stubble to stand to be turned under later by normal fall or spring plowing.

Fall disking.—In the early development of dry farming, disking of the stubble land immediately after harvest was advised, and in some

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director. Presented at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication November 21, 1930.

[2]Superintendent, Nephi Dry-farm Sub-station, and Agronomist, respectively.

sections the practice is still followed to a small extent. Unquestionably, some of the reasons for disking have value, such as the advantages to be derived from covering weed seed and shelled grain, but some of the other reasons advanced are probably not valid. Tests to determine the comparative value of disking have been in operation since 1916. The average wheat yield from fall-plowed land undisked over the 14-year period from 1916 to 1929, inclusive, was 26.1 bushels. For land disked followed by fall plowing the average yield was 24.6 bushels. The same comparison for spring plowing shows 25.1 bushels for land not fall disked and 22.5 bushels for fall disking. In each case there is not only no gain, but an actual loss due to fall disking.

Disposal of stubble.—Burning of the stubble either in the fall or in the spring is not a common practice on the dry-lands of the Great Basin, but in certain of the wheat areas of western United States it is not uncommon. The average acre yield over the 14-year period from 1916 to 1929, inclusive, for burning all of the straw is 24.7 bushels, whereas the corresponding tillage treatment with all the straw plowed under gave an average acre yield of 23.4 bushels. Plats on which only the high stubble was burned yielded 25.2 bushels as compared with 24.5 bushels for the high stubble turned under. These differences, while not great enough to be significantly favorable to burning, are rather consistent over the entire 14-year period. While yearly burning of stubble is perhaps inadvisable, yet there may be reasons for burning once in several seasons, and these data indicate that no harmful effect is likely to follow, at least under present conditions.

Time of plowing.—Of all tillage operations connected with wheat growing on dry land, time of plowing is by far the most important, provided weeds are kept under control on fallow land. The success or failure of dry farm cropping in the Great Basin, as far as profitable returns are concerned, rest upon this practice. A test to compare fall and spring plowing has been in operation at Nephi since 1903. Beginning in 1916 this was supplemented by delayed spring plowing. Because of the variability of the spring seasons at Nephi no definite date was set for the different times of plowing, but instead somewhat definite growth stages of the weed and volunteer growth were used. The average acre yields covering the 14-year period from 1916 to 1929, inclusive, follow:

Fall plowing	23.5 bushels
Early spring plowing	24.4 bushels
Plowing when volunteer wheat was 6 inches high	20.3 bushels

Plowing when volunteer wheat was 12 inches high	17.8 bushels
Plowing when wheat plants were in bloom........	14.6 bushels
Plowing when wheat plants were in milk stage..	13.0 bushels

The variation between fall and early spring is so small as to be of no significance. The highly significant reductions in yield are connected with delayed spring plowing.

Depth of plowing.—A depth-of-plowing experiment has been under test at Nephi since 1910. The average results in yields per acre for the 20-year period are as follows:

Plowed 5 inches deep........................	22.7 bushels
Plowed 8 inches deep........................	25.2 bushels
Plowed 10 inches deep........................	25.0 bushels
Subsoiled 15 inches deep......................	24.1 bushels
Subsoiled 18 inches deep......................	23.9 bushels

The year 1913 came nearer being a failure for wheat at Nephi than any other year before or since. The acre yields of that particular season are as follows:

5-inch plowing............................	10 bushels
10-inch plowing............................	7 bushels
15-inch subsoiling..........................	6 bushels
18-inch subsoiling..........................	4 bushels

With the exception of 1922, this tendency is noted in every year of low yields since the beginning of the test. Clearly, if maximum returns are to be secured and if costs are to be kept down, deeper or shallower plowing than 5 to 8 inches has no place on Utah dry farms where the texture of the soil is a clay loam.

Treatment of summer fallow.—At one time it was thought that harrowing immediately after plowing followed by frequent harrowings during the summer was necessary for profitable dry-farm yields. Rigid weed control on fallow land cannot be too strongly stressed, but data from the Nephi Sub-station indicate that just enough cultivation to control weeds is required. The following averages cover the 14-year period from 1916 to 1929, inclusive:

Ordinary cultivation of fallow	
Fall-plowed..............................	26.1 bushels
Spring-plowed............................	25.1 bushels
No tillage of fallow—weeds hoed	
Fall-plowed..............................	24.2 bushels
Spring-plowed............................	25.1 bushels
Fallow cultivated frequently	
Fall-plowed..............................	23.9 bushels
Spring-plowed............................	24.3 bushels

Comparing ordinary fallow with that left uncultivated, the average yields for spring plowing are identical, *viz.*, 25.1 bushels per acre. The same comparison for fall plowing shows a difference of approximately 2 bushels in favor of normal tillage. Frequent tillage either depressed the yields or had no influence whatever. It seems, therefore, that cultivation of fallow beyond a certain limit is a waste of time, since weed control is the essential end to be accomplished.

SEEDING EXPERIMENTS

Rate- and date-of-seeding experiments.—Rate and date of seeding on dry land has become fairly well standardized. The rate of seeding wheat on clay loams is regularly 5 to 6 pecks per acre, with less on lighter soils. While there is some little variation in date of seeding, most of it is finished by October 1, or soon thereafter.

The rate- and date-of-seeding test at Nephi consists of sowing from 2 to 8 pecks, inclusive, on August 1 and 15, September 1 and 15, October 1 and 15, and on November 1. The following results in bushels of winter wheat per acre are averages for all rates of seeding for each date, covering the period from 1920 to 1929, inclusive:

August	1	20.2 bushels
August	15	19.9 bushels
September	1	19.9 bushels
September	12	22.2 bushels
October	1	22.9 bushels
October	15	22.2 bushels
November	1	22.6 bushels

These data indicate little difference in time of seeding during August and up to September 1. Between September 1 and 15 there is a difference of 2.3 bushels per acre in favor of the later sowing. Heavy semi-torrential showers coming during August and early September frequently cause a packing of the surface soil, thus preventing emergence of good stands of grain. This is in part responsible for the difference between sowings on September 1 and 15.

The following data are averages for all dates of sowing given for each rate:

Rate of seeding (pecks)	Net yield (pecks)
2	17.5
3	19.4
4	20.7
5	20.9
6	20.9
7	20.8
8	20.7

These results indicate regular increases in yield of wheat with the increased rates of seeding up to and including 4 pecks per acre. From

this point up to 8 pecks the differences are so small as to be negligible.

Spacing and cultivation test.—The bushel yields of winter wheat, as given in the following averages covering a 7-year period with rows 7, 14, 21, and 28 inches apart, for both the cultivated and uncultivated, show only slight variation for the widths greater than 7 inches, which is normal:

Spacings uncultivated	
14 inches	26.9 bushels
21 inches	26.3 bushels
28 inches	26.0 bushels
Average wide-spaced drillings	26.4 bushels
Average normal seeding (7 inches)	28.6 bushels
Spacings cultivated	
14 inches	24.7 bushels
21 inches	25.1 bushels
28 inches	24.3 bushels
Average wide spaced drillings	24.7 bushels
Average normal seeding (7 inches)	27.7 bushels

Type of drill.—The furrow drill which is now being used extensively in parts of the Great Plains has been compared with the common drill since 1923. The average acre yields follow:

Ordinary drill	27.7 ± .83 bushels
Furrow drill	26.9 ± .77 bushels

While the difference in wheat yields between the furrow drill and the ordinary type is so small that no importance can be attached to the difference, the data do indicate that the furrow drill probably has no place on the dry lands of the Great Basin where winterkilling and soil blowing are not encountered as definite problems in wheat growing. The extra power required for furrow drilling is also expensive.

Seed treatment for smut.—Certain smut disinfectants, especially formalin, are known to damage wheat to a point that yields are seriously reduced. Beginning in 1924 and continuing to 1929, a test has been in operation at Nephi to determine the effect of various treatments on yield. The results follow in bushels per acre:

No treatment	28.3 ± .85 bushels
Copper carbonate (dust)	27.7 ± .80 bushels
Copper sulfate	26.2 ± 1.01 bushels
Formalin	26.1 ± 1.55 bushels

CROPPING EXPERIMENTS

After three-quarters of a century of experience in which experimental work has had a directing hand during the better part of the

period, wheat growers on the dry lands of the Great Basin have come to the almost universal practice of alternate crop and fallow. Since 1903, a cropping test of winter wheat has been a part of the experimental procedure at Nephi, with the first results appearing in 1904. The data covering a period of 26 years follow:

	Total production, bushels	Crop yield, bushels
Continuous cropping	286.3	11.1
Alternate cropping	290.0	22.3
2 crops in 3 years	303.5	17.8
1 crop in 3 years	197.9	21.9

Continuous cropping has produced a total of 286.3 bushels with an average crop yield of 11.1 bushels. Alternate cropping has produced a total of 290 bushels or a crop yield of 22.3 bushels. Divided by years rather than by crops, the alternate practice gave an average acre-yield of 11.15 bushels— almost identical with continuous cropping. From these data it may be stated that under climatic conditions similar to those at Nephi alternate crop and fallow and requiring plowing only alternate years is safest. In regions with more moisture well distributed, two crops with one fallow may have significant advantages in production.

FERTILITY EXPERIMENTS

Most of the dry lands in the Great Basin are still comparatively virgin in relation to fertility. While a few dry farms have been cropped for over 50 years, most of the land now in wheat was in sage 30 to 40 years ago. With a cropping system of alternate wheat and fallow, and with the straw returned to the land, the fertility of the dry lands should maintain maximum yields over a long period of time. This is likely true for all of the elements, with the possible exception of nitrogen which is normally low.

Looking ahead to the future possible needs of dry farming in connection with fertility, two projects were added in 1915, *viz.*, the application of barnyard manure in various quantities and at various times; and plowing under green manure crops, such as peas and wheat, at different intervals of growth.

Application of barnyard manure.—On the basis of the application of the manure this test is divided into three parts as follows: (1) Various amounts of manure applied each alternate year, (2) different quantities of manure applied every 4 years, and (3) manure applied in certain definite amounts in 1915, with no later applications.

For the alternate application of manure, the data by 5-year averages, with final averages, are given in Table 1. These data show

that the soil did not respond to the small amounts of manure. For the larger amounts of manure, it is apparent that for the first 5 years 5 tons of manure showed little increase, most of the increased yield coming in the second and third periods. With 10 tons the increased yield of wheat was quite regular, with the greatest increase coming in the first and second periods.

For manure applied every four years the yield data by 5-year averages are given in Table 1. An inspection of each average shows an increased yield of wheat due to the application of manure as compared to the check. Where 2.5 tons of manure in the previous test produced no effect, the experiment showed gains which are likely consistent. With the large applications of manure the greatest percentage of increase came in the first two periods. As compared to the check, the last 5-year period showed no progressive gain in percentage over the second period. The same tendency was also characteristic of the alternate applications, although not so pronounced.

TABLE 1.—*Average yields of winter wheat in bushels per acre, giving the total and three 5-year periods from 1915 to 1929, inclusive, produced from various amounts of barnyard manure applied at various times.*

Tons of manure	1915–19		1920–24		1925–29		Average	
	Average yield	Relative yield, check 100	Average yield	Relative yield, check 100	Average yield	Relative yield, check 100	Average yield	Relative yield, check 100
				Applied in alternate years				
None	18.9	100	24.0	100	27.4	100	23.4	100
1	18.0	95	23.6	98	27.0	98	22.9	98
2.5	17.8	94	23.5	98	29.7	109	23.7	101
5.0	19.6	103	26.5	110	31.9	116	26.0	111
10.0	21.0	111	29.3	122	34.7	126	28.3	121
				Applied every 4 years				
None	17.7	100	21.4	100	26.0	100	21.7	100
2.5	18.3	103	23.4	109	28.2	108	23.3	107
5.0	19.7	111	24.7	115	30.3	116	24.9	114
10.0	20.4	115	26.9	125	32.9	126	26.7	123
				Applied in 1915, none later				
None	18.9	100	24.0	100	27.4	100	23.4	100
2.5	19.4	103	24.1	102	27.2	100	23.6	102
5.0	20.3	111	24.1	103	28.2	104	24.1	105
10.0	19.7	109	24.2	104	28.0	104	24.0	106
15.0	21.1	118	24.7	106	28.7	107	24.8	111
20.0	20.7	119	25.0	109	29.4	111	25.0	112
None	17.1	100	22.7	100	26.3	100	22.0	100

The results of the third test having to do with the residual effect of barnyard manure on wheat yield are also given in Table 1. As the yields indicate, all applications of manure made in 1915 with none

later showed an effect in the first 5-year period with increasing value for the larger amounts of manure. In the next 5-year period the percentage gains in wheat yield were more than cut in two, with the exception of the 2.5-ton application, thus showing a gradual decrease in the residual effect. In the third and last period the 2.5-ton application lost its effect, thus indicating that the larger amounts of manure produced an effect through 10 years and on into the period between 10 and 15 years.

Briefly, the foregoing data indicate that manure applied to dry land in moderate amounts, i. e., 10 tons each alternate year or each four years, affects the yield beneficially to the extent of over 20%.

Green manuring.—Because of low precipitation, the dry lands have always supported a comparatively scant vegetative growth. This has been reflected in the soil to the extent that soils formed under arid conditions are low in organic matter. An experiment covering this problem with wheat and peas plowed under for green manure at various stages of growth was started in 1915. The average yields per acre for the 15-year period follow:

Peas plowed under when 6 inches high	23.1 bushels
Peas plowed under when 12 inches high	23.3 bushels
Peas plowed under when in bloom	22.0 bushels
Peas plowed under when in pod	21.4 bushels
Ordinary fall-plowed fallow	23.5 bushels
Wheat plowed under when 6 inches high	20.3 bushels
Wheat plowed under when 12 inches high	17.8 bushels
Wheat plowed under when in bloom	14.6 bushels
Wheat plowed under when in head	13.0 bushels
Ordinary fall-plowed fallow	23.5 bushels

The relation of wheat yields to green-manuring practice on the dry lands, as indicated by these yields, shows that any deviation from the ordinary practice of crop and fallow with fall or early spring plowing for fallow is not justified. While no appreciable reductions in yield of winter wheat followed peas used as green manure, yet when the extra labor of seeding the peas and the cost of seeding is considered the practice is not justified. The reductions in yield of wheat following wheat as green manure were so pronounced as unqualifiedly to condemn such a practice.

ROTATION EXPERIMENTS

In the early development of dry farming in Utah, the system of cropping was not standardized, as is the case today. The continuous growing of wheat was in rather common practice in some areas and was continued until about 20 to 30 years ago. At present,

alternate crop and fallow is generally followed with a few areas having the possibility of replacing the fallow with a cultivated crop, such as peas, potatoes, corn, or beans.

The average results of one of the rotations established at Nephi in 1908 follow:

Wheat	21.2 bushels
Corn (fodder)	1,107.0 pounds
Wheat	21.3 bushels
Potatoes	26.1 bushels
Wheat	21.8 bushels
Peas	3.6 bushels
Wheat (average for rotation)	21.4 bushels
Wheat alternating with fallow	23.4 bushels

The average yield of wheat after intertilled crops has been surprisingly uniform, slightly above 21 bushels, with wheat after fallow about 2 bushels higher.

The average yields of another rotation started in 1915 are as follow:

Peas after fallow	3.8 bushels
Peas after wheat	4.0 bushels
Corn after fallow	899.0 pounds
Corn after wheat	1,422.0 pounds
Potatoes after fallow	19.7 bushels
Potatoes after wheat	22.7 bushels

The slight difference which favors peas and potatoes in rotation with wheat as compared to peas and potatoes after fallow is highly significant in favor of corn after wheat as compared to fallow. The probable reason for such a reaction is an organic relationship which apparently overbalances the extra moisture carried by the fallow land.

A TOTAL CARBON PROCEDURE[1]

ERIC WINTERS AND D. C. WIMER[2]

The conventional organic combustion methods owe their slowness to the need of placing the sample in a cool furnace, waiting for the furnace to heat, and lastly, after ignition, allowing the furnace to cool for the next sample. Because the organic content of soils is low and the compounds relatively inert and non-explosive, it was possible to devise a method[3] in which the need for cooling the furnace was eliminated. As a result, the time required for a determination was greatly reduced. It seemed probable that with suitable modifications this rapid method could be extended to the determination of carbon in plant materials which are for the most part cellulose compounds. Such modifications would need to include: (1) A means of moving the loaded boat from the cool part of the tube, outside the furnace, to the center of the furnace after all the connections have been made and the oxygen flow started; and (2) an active catalyst in large enough quantity to insure oxidation even under extremely rapid flow of combustible gases. It will become apparent after the description of the apparatus that such changes will also facilitate soil carbon determinations.

APPARATUS

The set-up is shown in Fig. 1. A 36-inch combustion tube is used, either clear quartz or silica with the exposed 11-inch section at the left of clear quartz so that the progress of the oxidation may be observed. A two-unit furnace is necessary. The first unit for igniting the sample is maintained at 950°–1000°C; the second, containing the catalysts, is not heated above 850°C in order that the tube shall not fuse with the copper catalyst and break. Two catalysts are used, cerium oxide and copper, the latter of course becoming copper oxide when the unit is heated the first time. About 2 inches of the tube are occupied by 20-mesh pumice bearing cerium oxide prepared as described by Fisher.[4] This is held in place against the 10-inch section of tightly rolled copper gauze by a short plug of copper gauze. A

[1]Contribution from the Division of Soil Physics, Department of Agronomy, University of Illinois, Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication November 25, 1931.

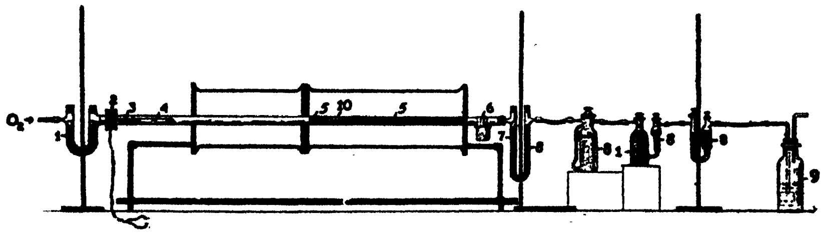
[2]Assistant and Assistant Professor, respectively.

[3]WINTERS, ERIC, and SMITH. R. S. Determination of total carbon in soils. Jour. Ind. Eng. Chem., Anal. Ed., 1: 202. 1929.

[4]FISHER, HARRY L.. Laboratory Manual of Organic Chemistry. New York: J. Wiley & Sons. 1924.

cooling cup and wick are used at the right extremity of the tube to prevent burning the rubber stopper.

The magnetic device for moving the boat into the furnace consists of: (1) A solenoid or coil that will fit over the tube and slide freely thereon; and (2) a small piece of iron or steel to which is attached a 4-inch piece of "nichrome" wire shaped into a flat disk-like coil at the end to act as a "pusher." The solenoid is conveniently operated from a 110 volt circuit which should produce a sufficiently strong magnetic field if the coil has a fair number of turns.



1-ASCARITE 6-COOLING CUP
2-COIL 7-ZINC
3-PUSHER 8-ANHYDRONE
4-BOAT 9-BUBBLE COUNTER
5-COPPER GAUZE 10-CeO_2 ON PUMICE

FIG. 1.—The apparatus.

TECHNIC WITH SOIL SAMPLES

The procedure for soils is essentially the same as described by Winters and Smith, except for the manner of introducing the sample. This is accomplished as follows: The loaded boat is so placed in the tube with the "pusher" behind it that the boat lies outside the furnace, as in Fig. 1. Next, all connections are made and the oxygen flow is started. The coil is then centered over the iron core, the circuit made, and the boat pushed to the center of the first unit of the furnace. The "pusher" is then pulled back to its original position and the current turned off. The time required for a determination, the size of sample, the use of manganese dioxide, and other details have all been discussed in the previous paper and need not be repeated here. The magnetic insertion of the charge, the chief difference in the modified method, reduces the chance of gas losses and for this reason is preferable for use by less experienced analysts.

TECHNIC WITH PLANT MATERIAL

Several hundred samples of the leaves and stalks of mature corn plants have been analyzed for carbon in this apparatus and the procedure to be described will apply primarily to such material.

The furnaces are brought to the proper temperatures, the train flushed with O_2, and a blank run. A sample of 0.1000 gram or less of thoroughly dried, finely cut material is weighed out and transferred to a 90-mm alundum combustion boat. The boat, with the "pusher" behind it, is placed in the tube, the connections made, and the oxygen flow started. The coil is centered over the iron core before turning the current on. This prevents the "pusher" from jumping violently and moving the boat from the desired position. With the current on, the boat is moved toward the furnace until the front end is just past the edge, leaving most of the boat outside the furnace. This position will need to be varied somewhat, depending on the heat distribution of the furnace. If the boat has been properly located, the material in it will start to give off its volatile materials in 1 or 2 minutes. When these volatile gases appear, the oxygen flow should be so regulated that the gasses are swept into the furnace without reaching the top of the tube. A rapid flow of oxygen must be used to accomplish this, 15 liters or more per hour. Often the material will catch fire before it is charred, especially if the boat is a little too far in the furnace. However, condensation will not usually occur on the cooler portion of the tube just without the furnace if the gas flow is rapid unless (1) the boat has been placed so far in the furnace that the heat is sufficient to cause an explosion, blowing the gases back; or (2) the boat is too far away from the furnace, thus allowing the volatilized material to condense on the surface of the tube before reaching the furnace.

When the material is charred, the boat is moved to the center of the furnace, the "pusher" brought back to its original position toward the end of the tube, and the coil current turned off.

If, during the above process, some condensation of volatile products has occurred due to improper placement of the boat or incorrect control of the gas flow, the condensed material can readily be disposed of by flaming those portions of the tube affected with a bunsen burner. The material is revolatilized by the flaming and passes on to the furnace where it is oxidized. The resulting CO_2 can then be caught and weighed with that of the rest of the sample.

After the boat has been in the furnace about 10 minutes, the oxygen is turned off, the stop-cocks on the absorption bulb closed, and the boat containing the ash removed with a hooked "nichrome" wire or furnace rake. The apparatus is then ready to start another determination following the same procedure as above.

NOTES

A blank is run before starting any determinations and thereafter at intervals. The blanks should be both low, about 0.0008 to 0.0014 gram CO_2, and fairly constant. If they are not, the cause should be looked for in poor connections, failure to keep the furnace rake, pusher, and boat free of dust, condensed material on the tube, or burning stopper.

It was observed that after combustion the ash occasionally appeared black in places as though the carbon had not been completely burned. This black coloration occurred most frequently in the ash of samples high in silica. The conclusion was reached that this coloration might not be carbon, for on replacing such ashes in the furnace, they failed to yield any carbon dioxide or to change color, even though ignition was continued one hour. Furthermore, the use of manganese dioxide in the bottom of the boat, as is recommended for soils by Winters and Smith, failed to give significantly higher results than were obtained without manganese dioxide.

As the ascarite acquires a white coating ($NaHCO_3$ or Na_2CO_3), the absorption of CO_2 in that region is less rapid which results in the CO_2 passing further into the bulb before absorption is complete. As this white layer approaches the lower portion of the bulb there is danger that the CO_2 may not be completely absorbed because of the very rapid gas flow that sometimes occurs. Therefore, it is desirable to renew the ascarite at frequent intervals.

The granulated zinc and anhydrone in the first tube should be changed about once a day when the apparatus is in constant use. Any anhydrone that is not moist may be used again but only in the first tube with the zinc. If this practice is followed, the anhydrone in the second tube needs be renewed only at infrequent intervals.

ACCURACY AND PERCENTAGE OF ERROR

The precision of the balance when weighing an absorption bulb is estimated at $\pm$ 0.0002 gram. Since the weight of the CO_2 is found by subtracting two weighings, the possible error in CO_2 weight will be $\pm$ 0.0004 gram. Assuming an average yield of 0.1600 gram CO_2, the error in this quantity is $\frac{4}{1600} \times 100 = 0.25\%$. The error involved in weighing and transferring a 0.1000 gram sample should fall within the range $\pm$ 0.0003 gram which gives $\frac{3}{1000} \times 100 = 0.30\%$ error. The equation for the percentage of carbon is $\frac{\text{Wt } CO_2 \times 12 \times 100}{\text{Wt. sample} \times 44}$. It is

seen that the above-mentioned quantities both appear as factors, hence the percentage of error in the result will be the sum of the percentage of errors in each factor, or ± 0.55%. Two carefully conducted determinations of the same sample then can be expected to differ as much as 1.10%.

TABLE 1.—*Carbon determinations showing the degree of accuracy of the method.*

Sample and No.	Sample weight (water-free material), gram	CO_2, gram	Blank, gram	Blank subtracted, gram	C, %	Difference between duplicates: CO_2, gram	Difference between duplicates: C, %	Variation from mean, %
Corn leaves, 527	0.1000	0.1608	0.0009	0.1599	43.58	0.0028	0.76	0.86
		0.1635		0.1626	44.34			
Corn leaves, 538	0.1000	0.1565	0.0013	0.1552	42.32			
		0.1566		0.1553	42.35	0.0001	0.03	0.04
Corn leaves, 552	0.1000	0.1592	0.0011	0.1581	43.11	0.0008	0.22	0.26
		0.1600		0.1589	43.33			
Corn stalks, 66	0.1000	0.1667	0.0010	0.1657	45.19			
		0.1681		0.1671	45.57	0.0014	0.38	0.42
Corn stalks, 77	0.1000	0.1676	0.0013	0.1663	45.35			
		0.1667		0.1654	45.11	0.0009	0.24	0.26
Corn stalks, 92	0.1000	0.1645		0.1633	44.53			
		0.1628	0.0012	0.1616	44.07	0.0017	0.46	0.52
Corn stalks, 124	0.1000	0.1686		0.1675	45.68			
		0.1692	0.0011	0.1681	45.84	0.0006	0.16	0.17
Salicylic acid	0.1000	0.2233		0.2225	60.68			
		0.2241	0.0008	0.2233	60.90	0.0008	0.22	0.18

Since determinations of nitrogen, calcium, phosphorus, and other elements with which carbon values are to be compared usually involve errors greater than 1.0%, it is suggested that an allowable variation between duplicates of 1.1% or less is satisfactory. Should the difference exceed this value, then it is well to repeat the determination, taking care that such faults in technic as slight losses of sample during transfer, loss of CO_2 thru exhausted ascarite, inactivation of the catalysts, and too rapid insertion of the boat into the furnace are not present.

In Table 1 are recorded data for several samples run in duplicate. The range of variation is representative of about what may be expected in a large number of determinations. The percentage difference from the mean (last column), which might be termed "observed error," is seen to range below 1.0, as expected from the above discussion.

The determination of the carbon in salicylic acid was successfully made, even though such materials are not recommended for analysis in this apparatus, and the results are recorded at the bottom of Table 1. The theoretical carbon content in this compound is 60.9%, which checks satisfactorily with the average of the observed values, 60.8%.

A METHOD OF LAYING OUT EXPERIMENT PLATS[1]

R. J. GARBER, T. C. MCILVAINE, AND M. M. HOOVER[2]

A few years ago additional land for agronomic experiments was obtained at the Lakin Experiment Station in West Virginia. The new area is adjacent to plats of the rotation experiment and located on the same type of soil—Wheeling fine sandy loam. A soil heterogeneity study similar to the one made of the plats now in the rotation experiments[3] was made on the new area preparatory to establishing field experiments with fertilizers.

PLAN OF THE FIELD

The plan of the field containing the new area, together with the rotation experiments, is shown in Table 1. The roadways running parallel with the plat series are indicated by double lines, and cross roadways are indicated by single heavy lines. All roadways are approximately 14 feet wide.

The plats for the fertilizer experiments, like the plats for the rotation experiments, were laid out in double series, each plat being 68 feet long and 21 feet wide, thus giving a gross area of about 2/61 of an acre. At harvest time a border about 3½ feet wide on the sides and ends of each plat is discarded, leaving a net area on which yield is based of 1/51 of an acre.

The blank plats in Table 1 appeared unsuited for fertilizer experiments and therefore yields were not obtained from them. The plats indicated in the last two sections of Table 1 with single numbers only are being used in the rotation experiments. The present soil heterogeneity study was made on all other plats shown in the plan.

CROPS AND METHODS

Three uniformity crops were harvested, as follows: Corn in 1927, oats in 1928, and wheat in 1929. Before planting the corn the entire area was limed at the rate of 2 tons of limestone per acre, but no fertilizer was applied while the uniformity crops were being grown. The yields per acre of stover and grain in the case of corn and of straw and grain in the case of wheat and of oats were determined.

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Presented at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Published with the approval of the director as Scientific Paper No. 95. Received for publication November 22, 1930.

[2]Head of Department and Assistant Agronomists, respectively.

[3]GARBER, R. J., MCILVAINE, T. C., and HOOVER, M. M. A study of soil heterogeneity in experiment plots. Jour. of Agr. Res., 33: 255–268. 1926.

All yields shown in Table 1 were based on the net area (1/51 acre) harvested from each plat. In addition, the wheat yields in 1929 were determined on the basis of 5 drill rows, each 14 feet long. The five single drill rows were taken at intervals of about 12 feet, beginning 6 feet from the end of the plat. The drill rows ran crosswise of the plats.

The yields computed were all expressed on an air-dry basis. The small grains were permitted to become thoroughly air dry before threshing and the corn was allowed to stand in the shock until air dry before husking. Samples of the ear corn were taken at time of husking in order to ascertain the percentage of moisture.

In the upper row, numbers in each rectangle representing a plat are deviations in percentage from the average yields of seed from corn, from oats, and from wheat, respectively, and occur in that order, reading from left to right. The lower row of numbers beginning at the left consists of the plat number, the replication number, and the average deviation in percentage of the yield of grain of corn and oats, i. e., the number obtained by averaging the first two percentages in the upper row. For example, the first plat in the upper left-hand corner of Table 1, for which data are available, is number 551. The difference between the yield of corn of this plat in 1927 and the average yield of all the plats for that year was —4.7% of the average yield. The negative sign indicates that this plat yielded less than the average. Similarly, the difference in yield of oats in 1928 between this plat and the average yield for that year was —13.4%. With wheat in 1929, plat 551 yielded 32.5% more grain, as is indicated by the plus sign, than the average yield of all the plats for that year. The replication number for plat 551 is 17. It may be observed that plats 759 and 903 also carry the replication number 17. These three plats will be handled as replicates in the fertilizer experiments. The last number in the rectangle representing plat 551 is —9.0, which is simply the average of —4.7 and —13.4, the deviations in percentage of the corn and oat yields, respectively.

CORRELATION BETWEEN YIELDS

By expressing all yields (grain, stover, and straw) as percentage deviations they are made directly comparable. No attempt was made to evaluate the degree of soil heterogeneity in terms of correlation coefficients as was done in the case of the uniformity crops preceding the rotation experiments. The plats of the present study, however, are adjacent to the plats in the rotation experiment and on the same type of soil. It is obvious, even from a cursory exami-

TABLE 1.—*Plan of plats, showing relative yields of grain of the three uniformity crops expressed in percentage deviations, plat number, replication number, and relative average percentage deviations in yields of corn and oats.*

	- 4.7-13.4+32.5 551 17 -9.0	+10.0+29.3+73.2 601 19.7	- 2.0+21.0+64.4 651 19 9.5	-11.6+ 7.0+32.5 701 8 -2.3	- 2.6+18.9+16.5 751 5 8.2	- 2.6+25.0+52.6 801 6 11.2	+10.1+21.3+48.5 851 23 15.7	- 3.5-8.8 901 18 -6.2	-7.6+9.1 951 30 -.8
	+ 0.7-25.9+10.8 552 11 -12.6	+ 6.7+39.3+68.6 602 23.0	+ 2.0+32.2+61.9 652 17.1	- 8.1+25.3+29.4 702 9 8.6	+ 5.4- 0.9+31.4 752 21 2.3	- 8.1+12.8+34.0 802 1 2.4	+ 0.1+24.1+51.0 852 24 12.0	+ 2.4+ 3.0+28.9 902 29 2.7	-11.4+22.0+14.9 952 21 5.3
	-11.0-38.7- 0.5 553 23 -24.9	+16.6+23.2+25.1 603 19.9	+ 4.2+24.7+49.0 653* 30 14.5	-11.6+21.0+30.4 703 4 4.7	-13.9+17.4+12.9 753 12 1.8	-21.6- 7.6+12.4 803 28 -14.6	-10.9- 3.0+17.0 853 25 -7.0	+ 3.4+18.6+21.6 903 17 11.0	+ 9.6+32.3+44.3 953 20.9
	- 8.5-35.7- 3.6 554 15 -22.1	+10.4+38.7+45.4 604 24.6	+ 5.3+ 7.9+33.5 654 29 6.6	+ 5.4+41.8+34.5 704 23.6	+ 7.9+11.0+35.6 754 3 9.5	- 3.7+ 2.7+12.9 804 27 -.5	+ 6.6+13.1+18.6 854 26 9.9	-13.8- 0.6+26.3 904 10 -7.2	- 3.2+15.2+25.8 954 14 6.0
	- 8.5-42.7+ 2.6 555 14 -25.6	+ 2.9-23.8+ 2.1 605 28 -10.5	-13.8+ 2.4+18.6 655 22 -5.7	-13.7+12.8+26.3 705 10 -.5	-12.2+ 7.3+20.1 755 20 -2.5	- 0.4+24.1+16.0 805 16 11.9	+14.6+18.0+17.0 855 15 16.3	-20.2-19.2-12.4 905 31 -19.7	- 2.1-13.7+ 8.8 955 22 -7.9
	- 3.3-31.7- 9.8 556 10 -17.5	- 8.3- 7.0+ 3.1 606 7 -7.7	- 6.7- 2.1+ 9.8 656 33 -4.4	-15.2-16.2+32.0 706 11 -15.7	- 6.3+ 8.2+40.2 756 19 1.0	+10.6+17.4+ 2.6 806 2 14.0	+ 5.1- 7.0-20.6 856 5 -1.0	-11.7-26.2-37.1 906 26 -19.0	- 0.1-15.9-12.4 956 7 - 8.0
	- 9.3-31.4+ 4.1 557 8 -20.4	- 2.1-23.8+10.8 607 6 -13.0	-12.7+ 8.8+11.9 657 25 -2.0	-17.7+ 8.8+23.2 707 12 -13.3	-34.0-29.0-15.5 757 1 -31.5	-27.7-36.3-33.5 807 9 -27.0	-26.5-49.4-31.4 857 -38.0	-12.5-33.8-32.0 907 27 -23.2	-10.1-39.0- 3.1 957 33 -24.6
	-27.6-58.8-25.8 558 -43.2	-32.1-30.5-22.2 608 5 -31.3	-17.7- 9.1- 3.1 658 20 -13.4	-17.0+ 5.5+ 9.8 708 13 -5.8	-29.8-14.6+ 7.7 758 18 -22.2	-18.7-20.1-21.6 808 24 -19.4	-11.4- 7.9+ 7.7 858 4 -9.7	+ 2.9- 7.9-11.9 908 8 -2.5	-15.6-29.6-26.3 958 6 -22.6
	-26.4-60.4-42.3 559 -43.4	-13.1-28.7-16.5 609 4 -20.9	-22.2-11.3- 1.0 659 26 -16.8	-20.9- 0.9+16.0 709 22 -10.9	-28.8-25.0- 1.5 759 17 -26.9	-26.1-33.5-18.6 809 30 -29.8	-19.1-16.8- 1.5 859 23 -18.0	-16.6-15.5- 9.3 909 25 -16.0	- 2.1- 4.6- 5.2 959 32 -3.4
+ 3.9+ 7.3+30.9 510 30 5.6	-10.9-22.3+ 2.6 560 24 -16.6	+ 0.7-22.9- 5.7 610 3 -11.1	- 0.3- 1.8-12.9 660 27 -1.0	- 6.0- 1.8-16.5 710 31 -3.9	-18.8-16.2-17.0 760 16 -17.5	-31.4-40.9-30.9 810 19 -36.2	-31.7-34.8-18.6 860 21 -33.3	-33.9-48.5-22.7 910 -41.2	-21.2-25.0-13.9 960 3 -23.1
+ 1.6-21.3+ 6.7 511 7 -9.9	+13.9-18.3-10.8 561 31 -2.2	-10.5-28.7-24.7 611 2 -19.6	- 9.5-15.5-17.5 661 12 -12.5	+ 3.8+ 3.4-17.0 711 11 3.6	-20.1-18.9-24.2 761 15 -19.5	-12.6-21.0-23.7 811 32 -16.8	-41.1-24.1-10.3 861 29 -32.6	-18.5-18.0-14.4 911 16 -18.3	-15.1-16.2- 5.7 961 13 -15.7
+15.5-16.8+11.3 512 28 -0.7	- 1.3-15.9+ 4.6 562 20 -8.6	+18.4- 7.3+ 2.6 612 1 +5.6	+11.0-17.7+14.9 662 32 -3.4	+ 2.4+ 6.1-10.8 712 33 4.3	- 2.1- 9.1- 6.7 762 14 -5.6	- 1.3- 5.2- 8.2 812 13 -3.3	-13.8-26.2-14.9 862 2 -20.0	- 8.1- 4.6+ 3.6 912 9 -6.4	+ 7.9- 0.9+22.7 962 18 3.5
+18.0-30.5+15.5 513 -6.3	+ 9.5-18.6+12.9 563 -4.6							-17.1- 9.8+15.5 913 3.7	+ 3.5-15.2+15.5 963 4.9

*Plat 653 was substituted for plat 951 in the fertilizer experiment because the latter was too narrow at one end.

+19.3− 4.0+ 2.1 514 7.7	+ 9.6−14.3+11.3 564 −2.4							− 9.3−31.4+ 5.2 914 −20.4	− 4.1− 5.2+20.1 964 −4.7
+ 8.7−16.2+14.4 515 −3.8	− 8.5−21 − 9.8 565 −14.8							− 0.7−16.2+13.4 915 −8.5	+ 1.1− 6.7+27.3 965 −2.8
+ 6.0 0.0+ 0.5 516 3.0	+ 8.0−11.6−11.9 566 −1.8							−21.4−40.9−64.4 916 −31.2	−24.4−25.9+ 2.6 966 −25.2
+ 8.9−16.8−12.9 517 −4.0	− 5.8−21.3− 5.7 567 −13.6							−43.2−39.9−57.7 917 −42.6	−28.4−32.6+ 4.1 967 −30.5
+10.5+ 2.4−12.9 518 6.5	− 9.3−13.4−19.6 568 −11.4							−32.6−42.4−33.0 918 −37.5	−33.6−29.0+ 1.5 968 −31.3
+ 8.8+11.9+13.9 519 10.4	+ 2.4− 5.2−11.9 569 −1.4							−22.7−40.5−22.7 919 −31.6	−48.8−30.8−12.4 969 −39.8
+ 9.5+11.0+17.5 520 10.3	+ 8.1+36.9+33.5 570 22.5							−19.4−27.7−24.7 920 −23.6	−48.9−42.7−12.4 970 −45.8
+ 3.9+17.1+16.0 521 10.5	+12.0+35.7+38.1 571 23.9							−35.9−28.0−22.2 921 −32.0	−30.6−37.2− 3.6 971 −33.9
+ 2.8+19.2+27.8 522 11.0	+ 6.8+10.4+22.7 572 8.6							−25.6−30.5−26.8 922 −28.0	−17.7−25.3−16.5 972 −21.5
+18.7+25.6+37.1 523 22.2	− 1.2+ 7.9+ 9.3 573 3.4							−16.3−21.0−21.6 923 −18.7	− 6.2−11.9− 9.8 973 −9.0
+18.5+41.2+52.6 524 29.9	+ 3.4+ 9.5+28.4 574 6.5							−13.9−14.3−13.9 924 −14.1	−18.3−18 −4.6 974 −18.2
+10.9+51.5+34.5 525 31.2	+ 4.6+18.0+12.9 575 11.3	+ 9.5+45.4+16.0 625 32.5	+20.2+32.6+60.8 675 26.4	+13.5+51.8+53.1 725 32.7	+ 7.2+13.7+40.7 775 46 10.5	+ 2.0+34.8+29.9 825 53 18.4	−10.6+ 4.0+11.3 875 50 −3.3	−10.1+15.5+ 3.6 925 2.7	− 4.3+2.1+ 0.5 975 −1.1
+ 6.0+16.5+12.9 526 11.3	+ 1.7+ 9.5+17.0 576 5.6	+ 6.3+28.4+ 6.7 626 34 17.4	+ 3.2+ 1.2+33.5 676 37 2.2	+ 4.5+21.6+33.5 726 56 13.0	+ 4.1+ 7.3+ 33. 776 52 5.7	+ 0.9+ 5.5+26.3 826 54 3.2	−13.4+19.8+10.8 876 55 3.2	−23.4+4.9+ 0.5 926 −9.3	− 1.3−13.4+ 1.0 976 −7.4
+ 5.9+19.5+18.0 527 12.7	− 3.2+2.7− 3.1 577 −.3	+15.6+28.0+23.7 627 35 21.8	+ 2.8+22.6+23.2 677 40 12.7	+ 3.9−22.6− 6.2 727 49 −9.4	−18.1−16.5+ 2.6 777 44 −17.3	−27.1−20.4− 7.7 827 48 −23.8	− 3.0−12.2− 9.8 877 47 −7.6	− 3.7−13.1−13.4 927 −8.4	−13.0− 9.1+ 4.6 977 −11.0

TABLE I.—*Continued.*

+15.9+ 7.9+21.6 528 11.9	- 9.3+12.5+ 2.1 578 1.6	+18.0+11.6+17.0 628 36 14.8	+ 9.9+43.0+33.5 678 26.4	-15.0-12.5+ 3.6 728 47 -13.8	-20.5-18.0- 3.1 778 50 -19.3	-35.5-35.4-27.3 828 -35.4	- 7.0+ 9.8+ 8.2 878 51 1.4	26.3+3.7+ 1.5 928 -11.3	-23.8+ 2.1- 3.6 978 -10.9
+ 5.4- 4.9+19.1 529 .3	- 8.7+ 7.0-10.3 579 -.9	+ 4.6- 5.8+1.0 629 41 -.6	- 2.8+11.0+16.5 679 39 4.2	-11.3- 5.8+ 6.2 729 55 - 8.6	-15.8-19.2- 8.8 779 48 -17.5	-42.6- 2.4- 8.2 829 45 -22.5	-24.4- 1.8- 6.2 879 56 -13.1	-42.8-16.8+0 .5 929 -29.8	-33.1 0.0+ 9.3 979 -16.6
- 3.8+ 7.6+16.0 530 1.9	-11.3+ 6.4+ 2.1 580 -2.5	- 9.7+ 9.1-16.0 630 38 -.3	-15.5- 6.4-12.9 680 42 -11.0	-14.1+ 4.3- 0.5 730 51 - 4.9	-16.3- 9.1-10.3 780 54 -12.7	-38.8-40.5- 6.2 830 -39.7	-21.7-19.5+32.0 880 52 -20.6	-26.5-21.6+26.3 930 -24.0	-23.5+19.2+ 9.8 980 -2.2
+11.0+ 5.2+14.4 531 8.1	- 16.7-6.4- 8.8 581 -11.6	-10.4+ 7.3+1.0 631 41 -1.0	-23.3-29.0-30.4 681 -26.2	-24.0 15.2-17.0 731 46 -19.6	-28.8-27.1-35.6 781 53 -28.0				
+13.7+45.4+43.8 532 29.6	-10.1+ 5.5+ 7.7 582 -2.3	-14.7- 3.4+ 5.2 632 34 -9.0	-20.4-15.2-24.2 682 37 -17.8	-18.5- 4.9+ 1.0 732 50 -11.7	-26.0- 6.7-19.6 782 49 -16.4				
+20.6-26.5+42.8 533 40 -3.0	+ 8.1+29.6+ 7.7 583 18.9	+ 7.1+22.3+ 9.3 633 39 14.7	- 8.9+ 7.9- 8.2 683 42 - 1.0	- 0.5+25.9+ 7.7 733 45 12.7	- 6.2+18.0+ 1.5 783 44 5.9				
+10.0+24.1+30.9 534 60 17.0	+ 1.1+15.2+16.0 584 73 8.2	- 3.9+19.5+18.0 634 38 7.8	-11.6+ 1.2-18.6 684 36 - 5.2	-12.5+ 1.2+ 7.2 734 49 -5.7	-20.6-16.2- 7.7 784 54 -18.4				
+13.5+39.6+27.8 535 87 26.6	+ 9.9+39.6+11.9 585 88 24.8	-12.6- 3.0+14.4 635 35 -7.8	-16.6+12.8-13.9 685 40 - 1.9	-19.3+40.2-14.9 735 48 +10.5	-25.4-24.1-11.9 785 52 -14.8				
+10.5+48.5+22.7 536 64 29.5	+ 5.4+26.2+ 4.6 586 80 15.8	- 6.4 0.0+12.4 636 36 -3.2	- 5.9+ 3.0-13.4 686 34 - 1.5	-16.4-13.1+10.3 736 47 -14.8	-23.7-14.6- 3.1 786 53 -19.2				
+19.6+39.0+33.0 537 71 29.3	+ 8.3+29.6+19.1 587 72 19.0	+ 6.4+27.7+22.2 637 37 17.0	-15.0- 8.8- 1.0 687 39 -11.9	-21.8-15.2- 2.1 737 46 -18.5	-28.6-22.6-14.9 787 55 -25.6				
+ 7.6+21.3+19.1 538 89 14.5	+12.0+34.5+19.1 588 66 23.3	+ 6.4+19.5+ 8.8 638 41 13.0	- 9.5+ 8.5+ 1.0 688 38 - .5	-20.4-16.8+ 6.7 738 45 -18.6	-30.9-27.7- 4.1 788 51 -20.3				
+1.6+17.4- 5.7 539 61 9.5	+15.5+21.6+ 5.2 589 85 18.6	+10.2+21.3+18.0 639 42 15.8	- 4.7- 7.0-11.3 689 35 - 5.9	-17.3-20.4-10.3 739 44 -18.9	-31.3-31.1+ 3.1 789 56 -31.4				
+12.7+25.3+30.4 301 67 19.0	+17.1+25.9+ 6.2 351 69 21.5	+13.5+37.8- 0.5 401 63 25.6	+ 2.6+25.3+ 2.1 451 83 14.0	1	51	101	151	201	251
+ 7.8+34.8+32.5 302 75 21.3	+24.4+26.2+ 5.2 352 68 25.3	+14.1+24.4- 4.6 402 86 19.3	+16.4+29.3+ 1.0 452 90 22.8	2	52	102	152	202	252

+16.7+38.4+26.8 303 76 27.6	+11.4+46.3+25.8 353 74 28.8	+23.4+35.4- 9.3 403 65 29.4	+20.5+19.5- 3.6 453 84 20.0	3	53	103	153	203	253
+21.9+34.5+28.4 304 77 28.2	+28.1+45.7+29.4 354 36.9	+19.3+24.1+ 4.6 404 87 21.7	+14.1+14.6-11.9 454 59 14.4	4	54	104	154	204	254
+15.5+43.9+28.4 305 78 29.7	+17.5+45.1+14.9 355 70 31.3	+20.9+25.0+ 3.1 405 88 23.0	+15.8+ 0.6-17.5 455 64 8.2	5	55	105	155	205	255
+12.5+39.0- 5.7 306 58 25.8	+29.2+25.0+26.3 356 73 27.1	+17.0- 4.6-33.0 406 81 6.2	+18.5+12.2-29.4 456 82 15.3	6	56	106	156	206	256
+ 9.9+24.4-19.1 307 79 17.2	+12.9+14.6-16.0 357 72 13.8	+20.1+ 1.8-16.0 407 83 11.0	+ 9.9+ 4.9-26.3 457 76 7.4	7	57	107	157	207	257
+ 4.3+18.3-17.5 308 80 11.3	+16.6+27.7-28.9 358 66 22.2	+21.4+15.2-19.1 408 61 18.3	+12.9- 4.6-34.0 458 75 4.2	8	58	108	158	208	258
+ 4.2+ 9.5-28.4 309 81 6.9	+ 9.5+ 5.6-21.1 359 71 7.6	+19.7+13.4-16.5 409 79 16.6	+15.8+16.8-28.4 459 62 16.3	9	59	109	159	209	259
+ 6.4+ 2.7- 7.2 310 63 4.6	+13.9- 0.3-18.0 360 70 6.8	+12.5+ 6.7- 9.8 410 60 9.6	+15.4+ 6.1-29.9 460 86 10.8	10	60	110	160	210	260
+16.0+25.6- 3.1 311 62 20.8	+20.1+ 3.7- 4.6 361 69 11.9	+18.4+14.6-23.2 411 89 16.5	+13.4- 7.9-45.9 461 90 2.8	11	61	111	161	211	261
+16.6+14.3-20.1 312 82 15.5	+ 3.0- 5.8-14.9 362 68 -1.4	+ 6.6-11.3-24.7 412 87 -2.4	+18.9- 2.4-30.4 462 57 8.3	12	62	112	162	212	262
+15.8+18.0- 7.2 313 80 16.9	+17.5+ 9.8- 9.3 363 67 13.7	+15.5+ 7.3-10.8 413 59 11.4	+15.5-20.7-32.5 463 88 -2.6	13	63	113	163	213	263
+12.9+ 8.2-10.3 314 74 10.6	+ 8.8-11.9-13.4 364 66 -1.6	+11.3- 1.8- 7.7 414 84 4.8	+10.6+ 4.9-18.0 464 78 7.8	14	64	114	164	214	264
+17.5+22.6- 9.3 315 83 20.0	+13.9- 2.1- 1.5 365 65 5.9	+28.0+34.1- 2.6 415 57 31.0	+ 8.3+11.0-24.7 465 85 9.7	15	65	115	165	215	265
+12.7+12.5- 1.0 316 77 12.6	+ 9.5+ 3.7+ 6.7 366 64 6.6	+25.1+36.9+27.3 416 81 31.0	+12.5+ 9.1- 9.8 466 79 10.8	16	66	116	166	216	266

TABLE I.—*Concluded.*

+21.6+19.8–18.6 317 84 20.7	+23.7+ 6.4+ 4.1 367 63 15.0	+16.0+16.5+ 4.6 417 58 16.2	+11.3+ 1.2–11.3 467 70 6.3	17	67	117	167	217	267
+13.7+ 7.0–12.9 318 69 10.3	+21.7+ 4.9+ 7.7 368 86 13.3	+18.0+11.0+ 5.7 418 82 14.5	+22.9– 5.5–18.6 468 76 8.7	18	68	118	168	218	268
+14.2+ 2.4– 5.7 319 65 8.3	+12.5+19.8+10.3 369 61 16.2	+ 7.1+17.7–21.1 419 72 12.4	+15.6+13.4–16.0 469 89 15.0	19	69	119	169	219	269
+11.7+11.6+ 3.1 320 67 11.6	+13.0+19.8+12.9 370 60 16.4	+ 6.8+2.1– 2.6 420 74 4.5	– 0.9– 7.0–45.9 470 –4.0	20	70	120	170	220	270
+ 7.4+24.1+19.6 321 85 15.7	+16.4+23.5+ 4.1 371 59 20.0	+23.5+17.1–10.3 421 68 20.3	+13.4+ 0.6–28.4 471 78 7.0	21	71	121	171	221	271
+ 9.9+28.0+20.1 322 75 19.0	+ 4.3– 1.8– 9.8 372 58 1.3	+11.3–3.7– 3.1 422 77 3.8	+3.8–11.3–23.2 472 73 7.6	22	72	122	172	222	272
– 1.3+15.9+10.3 323 71 7.3	+10.1+ 0.9 0.0 373 57 5.5	+22.1+15.2– 3.1 423 90 18.6	+27.5– 7.6– 7.2 473 62 10.0	23	73	123	173	223	273
+19.2+ 3.7–16.5 324 101 11.5	+17.2+16.8+12.9 374 17.0	+14.8–16.5–10.3 424 107 –.8	+21.0– 5.5–34.5 474 112 7.7	24	74	124	174	224	274
+15.6+14.0–13.9 325 94 14.8	+14.3+11.6+ 6.7 375 97 13.0	+12.5+26.8– 8.2 425 19.7	+ 5.0 0.0–18.6 475 108 2.5	25	75	125	175	225	275
+ 9.2+ 9.8–23.7 326 98 9.5	+ 9.5– 1.2–13.9 376 95 4.2	+13.3+25.9+11.9 426 19.6	+ 4.1– 0.3–25.3 476 106 1.9	26	76	126	176	226	276
+12.0– 2.4– 9.3 327 96 4.8	+12.0+ 2.1–12.4 377 99 7.0	+15.5+22.9+4.6 427 19.2	+ 1.1– 4.0–77.8 477 111 –1.5	27	77	127	177	227	277
12.5+17.1+20.6 328 91 14.8	+12.9+ 3.0–10.3 378 93 8.0	+16.3+17.7+13.4 428 17.0	+ 8.7+ 6.1–27.8 478 109 7.4	28	78	128	178	228	278
11.7– 3.7– 9.8 329 100 4.0	+10.1–23.8–13.9 379 92 –6.8	+12.4+12.8–15.5 429 103 12.6	+ 7.0– 4.0–48.5 479 112 1.5	29	79	129	179	229	279
+10.5+ 0.6– 7.7 330 95 5.6	+ 8.0–21.6–36.6 380 94 –6.8	+ 7.1+ 2.4–25.8 430 110 4.7	+ 5.8–10.7–47.4 480 105 –2.5	30	80	130	180	230	280
+10.8– 2.4–19.1 331 91 4.2	+ 8.9–14.0–29.4 381 98 2.5	+12.5– 3.0–37.1 431 104 4.7	+10.5– 4.0–57.7 481 106 3.3	31	81	131	181	231	291

+ 6.3- 4.3-56.2 332 101 1.0	+ 6.7- 4.3-33.5 382 97 1.2	-10.4-21.6-43.3 432 -16.0	+ 2.0+ 9.5-34.0 482 107 5.7	32	82	132	182	232	282
+ 6.2- 5.8-53.6 333 100 .2	+ 9.9- 2.1+ 2.1 383 93 3.9	+ 0.5-12.8-21.6 433 102 -6.1	+ 6.7- 5.5-29.4 483 111 .6	33	83	133	183	233	283
- 1.1-13.4-33.5 334 99 - 7.3	+16.3+ 1.2- 7.7 384 96 8.7	+ 6.7- 0.3-25.8 434 103 3.2	- 4.6-13.4-45.9 484 112 - 9.0	34	84	134	184	234	284
+ 5.1-17.4-11.3 335 97 - 6.2	+10.0+ 7.9-34.0 385 92 9.0	+15.8+ 6.4-13.4 435 104 11.1	- 0.8-12.8-39.7 485 109 - 6.8	35	85	135	185	235	285
+ 0.5-10.1-10.3 336 101 - 4.8	+ 3.3- 8.2-28.9 386 95 - 2.5	+17.3+10.4- 9.8 436 102 13.8	- 2.8-18.6-35.6 486 108 -10.7	36	86	136	186	236	286
+ 2.0- 8.5- 9.8 337 98 - 3.3	+ 8.4- 7.9-12.4 387 94 - .3	+14.3+ 5.2-19.1 437 105 9.7	- 4.5- 0.9-24.2 487 110 - 2.7	37	87	137	187	237	287
+12.6- 5.2+ 7.7 338 100 3.7	+ 2.9- 7.9-12.4 388 93 - 2.5	+ 6.6-18.9-27.3 438 106 - 6.2	- 0.4-14.0-27.3 488 102 - 7.2	38	88	138	188	238	288
+11.4-21.0- 2.6 339 96 - 4.8	+ 8.9- 0.9-10.3 389 92 4.0	- 0.4-13.4-30.4 439 107 - 6.9	- 5.3-26.5-18.0 489 104 -15.9	39	89	139	189	239	289
+11.7+ 6.7+28.4 340 99 9.2	+ 0.3-25.0- 5.2 390 91 -12.4	+ 2.4-17.4- 6.2 440 105 - 7.5	- 4.6-26.2-26.3 490 103 -15.4	40	90	140	190	240	290
+16.2- 3.7+27.8 341 6.3	- 0.9-11.0+ 0.5 391 - 6.0	+15.5- 0.9+ 9.8 441 108 7.3	+ 3.5- 9.1+10.3 491 110 -2.8	41	91	141	191	241	291
+13.4- 2.4+25.3 342 5.5	- 3.9-32.6-12.4 392 -18.3	+17.7-18.6+20.6 442 109 - .4	+10.1- 7.6+21.1 492 111 1.3	42	92	142	192	242	292
+17.1- 4.6+28.9 343 6.3	+ 3.9-25.6+21.6 393 -10.9	— —14.9+36.1 443	— —26.8+19.1 493	43	93	143	193	243	293
+ 7.0- 3.4+32.0 344 1.8	+20.1-17.4+40.7 394 1.4	— —33.2+24.7 444	— —18.0+24.2 494	44	94	144	194	244	294
+33.1-13.7+24.2 345 + 9.7	+16.4+17.1+48.5 395 16.7	— —28.7+37.1 445	— —17.7+27.3 495	45	95	145	195	245	295

Average yield of corn in 1927—76.1 bu.; of oats in 1928—32.8 bu.; of wheat in 1929—19.4 bu.

nation of Table 1, that soil heterogeneity existed in the area considered in the present study.

The correlations between the relative yields of the several uniformity crops are shown in Table 2. High correlations were obtained between the yields of corn in 1927 and of oats in 1928. For the grain yields based on 445 plats the correlation coefficient is + 0.58 ± 0.02 and for the stover and straw yields based on 411 of the same plats the coefficient is + 0.70 ± 0.02. In contrast, low correlations were obtained between the relative yields of corn in 1927 and the relative yields of wheat in 1929, the coefficient for the grain yields being + 0.20 ± 0.03 and that for the stover and straw yields + 0.33 ± 0.03. Finally, the correlations between the relative oat yields in 1928 and the relative wheat yields in 1929 were intermediate; the coefficient for the grain yields being + 0.50 ± 0.02 and that for the straw yields + 0.49 ± 0.03.

TABLE 2.—*Correlation between relative yields of uniformity crops grown at Lakin, W. Va., during 1927 to 1929, inclusive.*

Correlation between	n	r
Corn (grain) 1927 and oats (grain) 1928	445	+0.58±0.02
Corn (stover) 1927 and oats (straw) 1928	411	+0.70±0.02
Corn (grain) 1927 and wheat (grain) 1929	445	+0.20±0.03
Corn (stover) 1927 and wheat (straw) 1929	412	+0.33±0.03
Oats (grain) 1928 and wheat (grain) 1929	445	+0.50±0.02
Oats (straw) 1928 and wheat (straw) 1929	412	+0.49±0.03

The correlations between the yields of corn stover and both oats straw and wheat straw apparently were somewhat greater than the correlations between the grain yields of the same crops. On the other hand, the correlations for the grain yields and for the straw yields between the oats and wheat were approximately the same.

The wheat crop grown in 1929 was damaged considerably by winter injury. This may account, at least in part, for the somewhat lower correlation obtained between the relative yields of this crop and those of the other two crops. From the correlation surfaces showing the relation between the corn and wheat yields it was obvious that a greater degree of correlation existed between the lower-yielding corn plats and their subsequent wheat yields than between the higher-yielding corn plats and their wheat yields. For this reason the correlation surfaces of both the grain and straw yields were divided approximately at the middle of the range in relative corn yields, and the coefficients determined.

Between the higher relative corn yields and wheat yields the coefficient obtained for grain was + 0.05 ± 0.04 (n = 299) and for

straw + 0.16 ± 0.04 (n = 283). On the other hand, the coefficient obtained between the lower relative corn yields and the wheat yields for grain was + 0.33 ± 0.05 (n = 146) and for straw + 0.41 ± 0.05 (n = 129). The lower-yielding corn plats showed a higher correlation with the wheat yields of the same plats obtained two years later than did the higher-yielding corn plats.

ESTABLISHING REPLICATIONS

In view of the fact that the greatest correlation was obtained between the relative yields of the corn and oats crops and, further, that the wheat crop was damaged somewhat by winter injury, it was decided to use only the yields of the corn and oats in determining which plats should be replicates in the fertilizer experiments. Moreover, it has been shown elsewhere[4] that the yields of a uniformity crop of oats on this same type of soil were more closely correlated with the subsequent yields of different crops under various treatments than were the yields of a uniformity crop of wheat.

Seven more or less distinct fertilizer experiments were planned for the area available. In order to establish each treatment in triplicate the following numbers of plats were required for the seven experiments: 18, 27, 30, 42, 36, 81, and 102. Several possible uses may be made of the yields of the uniformity crops expressed as average deviations in percentage.

In the first place, those plats which show extreme average deviations in yields of corn and oats may be eliminated. The average deviations of the remainder of the plats could then be used as a basis for selecting replicates. It would seem desirable not only to have similar average deviation for each plat of a triplicate series but for each plat involved in a particular experiment. If a sufficient number of plats with similar average deviations was available to accommodate a particular experiment, then perhaps the ideal manner of locating plats would be at random or by some kind of restricted randomized selection. (It is hoped that this plan may be followed in a field now being studied for soil uniformity.) To obtain a sufficient number of plats with similar deviations within the area available to meet the requirements of even one of the experiments with the smaller number of plats would involve widely separated units and therefore result in considerable practical difficulty in carrying on the experimental work. The experiments requiring the greater numbers of plats could not be planned on this basis as a sufficient number of plats with similar average deviations was not available.

[4]GARBER, R. J., and HOOVER, M. M. Persistence of soil differences with respect to productivity. Jour. Amer. Soc. Agron., 22: 883–890. 1930.

Another plan considered for locating replicates was to classify the plats on the basis of average deviations into low-, medium-, and high-yielding groups and then to select, for each experiment, more or less at random, one plat from each group for the triplicated treatment. This plan, like the one discussed above, would involve considerable practical difficulty in carrying on the experimental work. Furthermore, this plan had no pronounced advantage over the one adopted with respect to variation among the three plats of a triplicated series.

In view of these considerations, and others which it is not necessary to discuss here, the plan which was finally adopted was to locate all the plats of a particular experiment in a more or less restricted area and in a manner so that the average deviations of triplicated plats in an experiment were of about the same magnitude.

The deviations in yield of grain for corn and for oats expressed in percentage and recorded in Table 1 were averaged and likewise recorded in the table. This average deviation was used in selecting replicates for the fertilizer experiments. An attempt was made to keep the algebraic sum of the average deviations of triplicate plats belonging to the same experiment approximately equal; also the triplicated plats were as widely distributed as possible over the area involved for a particular experiment.

An illustration may help to clarify the plan which was followed. In the first section of Table 1 the plats bearing the replication numbers from 1 to 27, inclusive, belong to the same fertilizer experiment. Plats 612, 757, and 802 are triplicates; similarly, plats 611, 806, and 862 are triplicates. Likewise, three plats may be found, each bearing the replication number 3; number 4; number 5; etc. The algebraic sum of the average deviations of plats 612, 757, and 802 is — 23.5; of plats 611, 806, and 862 is — 25.6; and of plats 610, 754, and 960 is — 24.7. Thus, the algebraic sums of the average deviations of triplicate plats belonging to this particular fertilizer experiment are as nearly equal as it was possible to make them and at the same time obtain a satisfactory distribution of the plats over the area involved. In other words, the deviations in yields obtained with the uniformity crops of oats and of corn were largely responsible for the location of triplicate plats. A similar procedure was used in establishing the plats of the other fertilizer experiments. The average potential productivity of triplicated plats belonging to a particular experiment as measured by the yields of corn and oats is thus approximately the same before the differential treatments are applied.

The authors are aware that the method of locating plats discussed here is open to the rather serious objection that the variance among triplicated plats is not uniform. On the other hand, if a consistent correlation is found between the yields of the uniformity crops and the yields of the crops grown later in the fertilizer experiments, it follows that a correlation will likewise be found between the variance within triplicated plats as revealed by the uniformity crops and the variance of the same triplicated plats as revealed by the yields

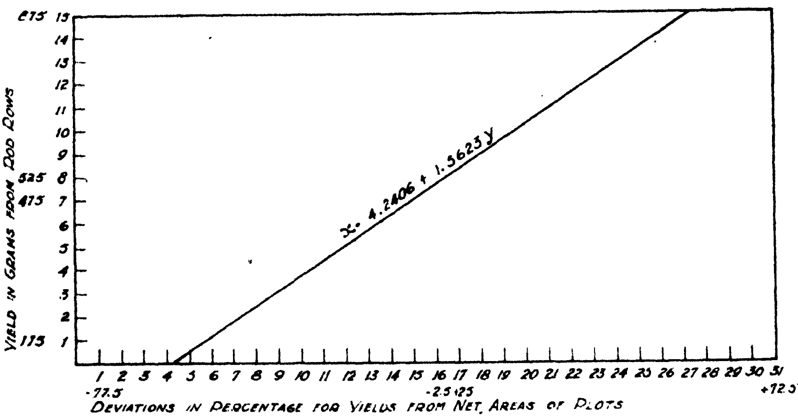


FIG. 1.—Regression of yield based on the net areas (1/51 acre) from plats on yield based on five rod rows removed from the same plats. (The authors are indebted to F. D. Cornell for drawing this figure.)

of the crops in the fertilizer experiment. By means of such a correlation it would be possible to estimate the amount of variance within triplicated plats attributable to the natural difference among the plats at the time the fertilizer experiment was begun and thus determine the amount of the residual variance or the variance commonly included under "error of experiment."

CORRELATION BETWEEN WHEAT YIELDS DETERMINED BY TWO METHODS

It was pointed out above that the yield of wheat in 1929 was determined by two methods. At harvest one drill row 14 feet long was removed from each of five different places in a plat. This material was dried and threshed to determine both the yield of grain and of straw.

After the five drill rows were removed from each plat the remainder of the wheat was harvested and threshed and the yields of grain and straw determined in the usual manner. The correlation coefficient obtained between the yields as determined from the five rod rows and

from the net area of the remainder of the plat was $+ 0.85 \pm 0.01$ ($n = 451$) for grain and $+ 0.84 \pm 0.01$ ($n = 450$) for straw. Both of these coefficients are high and indicate that the yield of the net area of a plat of wheat of the dimensions used in this study may quite accurately be predicted by computing the yields of five rod rows removed in the manner described. This agrees with a conclusion arrived at by Garber, McIlvaine, and Hoover.[5] The regression equation for predicting the yields of net areas of plats from yields determined by removing rod rows from the same plats is $x = 4.2406 + 1.5623y$. The regression line is shown in Fig. 1.

SUMMARY

A method for laying out triplicate plats for long-time field experiments is described. Three uniformity crops (corn in 1927, oats in 1928, and wheat in 1929) were harvested from an area involving something over 450 plats of 1/51 acre net each; and on the basis of correlation studies and other pertinent data, the relative yields of the corn and oat crops were used in establishing the location of replicated plats.

A high correlation coefficient was obtained between the yields of wheat as determined from five rod rows removed from each plat and the yields determined from harvesting the entire net areas of the same plats.

[5]*Loc. cit.*

SPRING TILLERING OF FALL-SOWN OATS[1]

C. K. McCLELLAND[2]

It often happens that fall-sown oats throughout the southern states are more or less severely injured by the freezing incident to the cold waves which sweep at times over the entire cotton belt region. This winter injury varies from 0 to 100% dependent on various factors, such as the date of planting, the fertility of the soil, the variety, the fall conditions, the growth activities of the plants, the severity of the cold waves, the cell sap concentration, the nature of any protection afforded, and who knows what else? To what extent do the oats make up in the spring for any depletion of stand resulting from winter injury? While there has been a general opinion that oats would tiller out in the spring, references on the subject are lacking. The present report is of investigations undertaken to secure more specific information on the subject.

Three main experiments were conducted, including plants transplanted to pots in the greenhouse, plants transplanted to the open field, and plants undisturbed in the field. Other considerations were (1) thickness of stand as represented by one, three, and five plants per pot and by various spacings in the field transplants; (2) the number of old tillers already on the plants, those containing from one to six tillers being taken both for the undisturbed and transplanted plants, though three-tillered plants only were used for pot, spacing, and fertilizer tests; (3) the influence, if any, of particular and combined fertilizing elements (not reported in this paper); and (4) the number of heads at harvest time and the percentage of heads from new or spring tillers.

POT EXPERIMENTS

Sixteen pots with different combinations of fertilizers were planted with one plant per pot, 16 with two plants per pot, and 16 with three plants per pot. Though three-tillered plants were used, later counts showed that often one or more of the tillers perished. In two pots transplantation did not succeed, while in several others one or more plants died. Table 1 gives the detailed counts on these transplanted plants. Table 2 summarizes the results, giving the original grouping and also the final groups with the two-plant and four-plant pots included.

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Submitted with the approval of the Dean of Agriculture as Research Paper No. 227, Journal Series, University of Arkansas. Received for publication November 28, 1930.

[2]Assistant Agronomist.

Some pots were thrown into the two-plant and four-plant groups through loss of one or more transplanted plants. It will be seen that

Table 1.—*Pot and fertilizer experiments in the greenhouse on tillering of fall-sown oats in the spring.*

Fertilizer per pot, grams*			Number of tillers per plant					
			1 plant per pot		3 plants per pot		5 plants per pot	
N (16%)	P (16%)	K (48%)	Mar. 1	Apr. 5†	Mar. 1	Apr. 5†	Mar. 1	Apr. 5†
			—	perish- ed	3-3-1	2-0 3-0	3-3-3-2-3	1-1-1-1-1 0-0-0-1-0
			3	2 3	3-3-3	2-2-0 4-5-0	3-3-3-3-3	1-1-2-1-1 0-0-0-0-0
0.55			3	3 2	3-3-2	2-2-0 2-3-0	1-2-3-3-3	2-1-1-2-0 1-0-0-0-0
0.55			3	3 13	3-3-2	2-1-2 4-3-3	3-3-3-1-3	1-1-1-1-1 1-1-1-0-0
	1.4		3	2 2	3-3-3	2-1-1 4-2-4	1-1-1-2-3	1-1-1-1-0 0-0-0-0-0
	1.4		3	2 5	2-2-3	1-1-0 0-0-0	2-3-3-3-2	1-1-1-2-0 1-0-0-0-0
		0.2	3	1 3		perish- ed	3-3-2-3-3	1-1-1-1-0 0-0-0-0-0
		0.2	1	1 1	3-2-2	1-1-0 0-0-0	2-2-2-3-3	1-1-1-1-1 1-0-0-0-0
0.55	1.4		3	3 3	3-2-2	1-0-0 3-0-0	3-3-3-3-2	1-1-1-2-2 0-0-0-0-0
0.55	1.4		3	1 0	3-2-1	2-0-0 0-0-0	3-3-3-3-3	2-1-1-1-1 1-2-1-0-0
0.55		0.2	3	1 1	3-3-1	2-3-0 2-3-0	2-3-3-1-3	1-1-1-1-1 0-0-0-0-0
0.55		0.2	3	2 2	3-3-3	2-1-3 0-1-1	3-3-3-3-2	3-1-1-2-1 0-0-0-0-0
	1.4	0.2	3	2 4	3-3-3	2-1-1 9-5-5	3-3-3-3-3	1-1-3-1-1 1-1-1-0-0
	1.4	0.2	—	perish- ed	3-2-3	2-2-0 7-5-0	3-3-3-2-2	1-1-1-1-1 0-0-0-0-1
0.55	1.4	0.2	3	1 2	3-3-3	2-1-1 6-4-4	3-3-3-3-3	2-1-2-2-2 1-1-0-0-0
0.55	1.4	0.2	3	3 3	3-1-3	2-1-0 6-4-0	3-3-3-3-3	1-1-2-1-3 3-1-0-1-1

*Fertilizers equivalent to respective elements in 600 pounds of 4-10-4 per acre.
†Upper figures represent old tillers; lower figures, new tillers.

with one, two, or three plants per pot there was an average of about three tillers per plant, but with four or five plants per pot new tillers occurred on but 30% of the plants. Crowding of the plants restricted the formation of new tillers.

These pots with the advent of warmer weather were set outside the greenhouse where they were emptied by mistake so that head records are not available.

TABLE 2.—*Summary of results in pot experiments.*

No. of plants per pot	No. of original plants	No. old tillers March 1	Notes of April 5			
			No. plants surviving	No. old tillers	No. new tillers	New tillers per plant
1	16	45	17	32	50	3.0—
2	0	—	14	24	41	3.0—
3	48	124	15	23	55	3.6+
4	0	—	12	15	2	0.2—
5	80	214	65	81	21	0.3+
Totals (or ave.).....	144	383	123	175	169	1.37

PLANTS TRANSPLANTED TO OPEN FIELD

A number of plants were transplanted to the open field about March 1, the land being disked thoroughly in preparation. The one-, two-, three-, four-, five-, and six-tillered plants were set out in separate blocks and several blocks were then set to three-tillered plants with different spacings. Table 3 summarizes the results in this test.

TABLE 3.—*Tillering records of plants transplanted to open field.*

Plat No.	Distance, inches	No. of plants	Original No. of tillers	Ave. No. new tillers	Ave. No. heads at harvest
	Plants with Different Numbers of Tillers				
1	6.5 x 6.5	102	1	2.62*	5.37
2	6.5 x 6.5	101	2	4.20*	7.02
3	6.5 x 6.5	116	3	4.91	7.54
4	6.5 x 6.5	114	4	4.71	7.97
5	6.5 x 6.5	116	5	5.45	8.46
6	6.5 x 6.5	118	6	4.79	8.20
	Plants Given Different Spacings				
7	4 x 4.3	188	3	2.15	3.23
8	6.5 x 7	133	3	3.59	4.95
9	9 x 10	135	3	7.84	9.21
10	11 x 12	114	3	10.25	10.69
11	5.5 x 6.5	128	3	5.27	6.43

*Number of heads at harvest indicates these records taken too early.

It seems as if the one-tillered plants had no "strength" and were unable to put on as many tillers as the plants having from two to six tillers. Many plants having 7 to 12 or more tillers were available

but were not used in this test under the impression that the greatest tendency to tiller would lie in those plants having small numbers of tillers. The five- and six-tillered plants, however, had high averages in new tillers and the highest average number of heads per plant at harvest.

In the spacing test, the results are quite consistent in showing increase in number of new tillers and in heads of grain with each increase given in the spacing.

RECORDS OF UNDISTURBED PLANTS

To check against the effect of the disturbance caused by transplanting, 50 plants in the field were staked for observation. These had each, one, two, or three tillers and were in stands made rather thin by the more severe winterkilling. Records on 47 of these were obtained. Table 4 gives the summary of the results.

TABLE 4.—*Spring tillering of undisturbed plants.*

No. of plants	No. of original tillers		No. of new tillers		No. of heads at harvest*	
	Total	Per plant	Total	Per plant	Total	Per plant
18	18	1	54	3.0	21	1.1
21	42	2	73	3.5	43	2.0
8	24	3	28	3.5	13	1.6
47	84	1.79	155	3.3	77	1.88

*Records from only 41 plants.

The average number of new tillers was 3.3 per plant, but the average number of heads at harvest was only 1.88. Observation on these and other plants showed that the larger heads were produced on the original culms. As compared with transplanted plants, whose record is found in Table 3, the undisturbed plants produced a less number of new tillers per plant and a much less average number of heads per plant at harvest time.

VALUE OF SPRING TILLERS IN SEED PRODUCTION

The fact that fall-sown oats may tiller in the spring is proved conclusively. There may remain a question as to the relative value of old and new tillers in seed production. Though the heads on the older culms may be larger, the number of new culms may be greater.

Inspection of the undisturbed plants showed that 82% of the heads were apparently from the older culms and 18% from the newer.

In counting the heads at harvest on the transplanted oats, a separate record of large heads and small heads was not kept. The number of heads at harvest, however, is shown to be from 1.4 (with

six-tillered plants) to 5.37 (in one-tillered plants) times the number of original tillers. In the spacing test the number of heads is from 1.07 to 3.56 times the number of original tillers, the number increasing with the increase in space allowed.

This shows that the spring tillers have a definite value in seed production, this value varying with the number of original tillers on the plant and the thinness of the stand.

The transplanted crop (Lee variety) was several days later than the undisturbed field crop, but tillering seems to have been favored by the transplanting method whether due to the transplanting or to the disking operations.

EFFECTS OF VARIOUS PLANT FOODS ON GROWTH ACTIVITIES AND DEVELOPMENT OF OATS[1]

C. K. McCLELLAND[2]

In connection with a study made on the spring tillering of winter oats, a different fertilization was given to various pots and rows to which the oats were transplanted.

The details of the planting in pots and individual plant records are given in an earlier paper.[3] It was thought preferable to include the effects of the different plant foods on the growth phenomena in a separate report. In the present report, along with the summary of these pot experiments, the records of two other tests are included. One of these was upon winter oats transplanted to the field and the other upon spring oats fertilized in the drill at planting time.

RESULTS OF POT TESTS WITH TRANSPLANTED PLANTS

In Table 1, are given the results of the pot experiments grouped according to treatments given and which are of value only as showing the relative effects of the elements nitrogen, phosphorus, and potassium on the tillering of the plants. The plants were of the Lee variety and uniform in type with one exception, *viz.*, that while most of the plants had from 0 to 6 tillers this one put on 13 new tillers and was apparently of the Turf type. When data on this plant are included in the averages, the results with applications of nitrogen or those including nitrogen are distorted to a certain extent. The average number of new tillers per plant with no treatment was 1.15; on all plants having nitrogen alone or in combination, 1.42; on all plants having phosphorus alone or in combination, 1.67; and on all plants having potassium alone or in combination, 1.42, indicating that in spite of the above advantage in favor of nitrogen, phosphorus causes the most tillering.

The highest rate of tillering (2.44 per plant) was in the pots having phosphorus and potassium and the lowest (0.36) in the pots receiving potassium alone. Those having nitrogen and potassium also showed a low rate of development, while those having nitrogen and phosphorus were but very little better.

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Submitted with the approval of the Dean of Agriculture as Research Paper No. 228, Journal Series University of Arkansas. Received for publication November 28, 1930.

[2]Assistant Agronomist.

[3]McCLELLAND, C. K. Spring tillering of fall-sown oats. Jour. Amer. Soc. Agron., 23: 299–303. 1931.

TABLE 1.—*Effect of stand and various plant foods on tillering of oats transplanted to pots in the greenhouse.*

Treatment	New tillers per plant			
	No. plants per pot			Ave. No. per plant
	1	3	5	
None	3.0	4.0	0.10	1.15
N	7.5*	3.0	0.44	2.13
P	3.5	2.0	0.10	1.20
K	2.0	0.0	0.10	0.36
NP	1.5	1.5	0.40	0.71
NK	1.5	1.4	0.00	0.60
PK	4.0	6.2	0.40	2.44
NPK	2.5	4.8	0.80	2.18

*One plant had 13 tillers, an exceptional number.

RESULTS WITH PLANTS MOVED TO NURSERY ROWS IN FIELD

A number of the same type of plants, as well as three-tillered plants, were moved into rod rows in the nursery area. These rows were 12 inches by 17 feet and the normal number per row was 25 which makes the spacing in each instance about 8 by 12 inches. No correction or allowance is made in these calculations for extra space which may have benefited plants adjoining areas where transplanted plants failed. However, the number of surviving plants is given for each row. One would expect, in view of results obtained from wide spacing reported in the previous paper,[4] that the increase in number of tillers and heads would be modified by proximity to such unused soil.

Table 2 gives the data in regard to formation of new tillers, number of heads at harvest, yield, weight per bushel, and size of seed from several different plans of fertilization on these nursery transplanted plants. Nitrogen and phosphorus, alone or together, and an ordinary application of complete fertilizer induced the greater tiller formation. Potash alone seemed to restrict the tillering, and when used with nitrogen alone or phosphorus alone there was also an apparent restriction which was not noticeable when all three were used together. However, when a double quantity of complete fertilizer was used the tillering was the same as if none were used.

The counts of heads at harvest time followed closely the average counts of new tillers. The use of phosphorus seems to insure a slightly larger number of heads. It will be noted that where none is used the number of heads is less than 10 per plant, while wherever phosphorus was used, alone or in combination, there were more than 10 heads per plant, the most being found in cases where nitrogen also was applied.

[4] *Loc. cit.*

TABLE 2.—*Effect of various plant foods on development of transplanted oats.*

Plat and row	No. 3-tiller plants surviving	No. old tillers surviving	No. new tillers put on	Ave. No. new tillers per plant	Ave. per plant per treatment	No. of plants at harvest	No. heads at harvest	Ave. No. heads per plant	Ave. No. heads per plant per treatment*	Weight per bushel, cup test (ave. of 4 tests)	Ave. wt. per bushel per treatment	No. seeds in 5 grams (ave. of 6 tests)	No. of seeds in 5 grams per treatment	Yields per rod row in grams	Ave. yield per treatment, per row
							No Treatments								
1–a	25	46	215	8.6	9.8	23	216	9.4	9.4	29.0	28.4	269	281	160	190
b	24	49	225	9.4		22	196	8.9		—		—		—	
c	21	51	237	11.3		21	208	9.9		27.7		293		220	
							Nitrogen								
2–a	22	46	222	10.1	10.3	22	230	10.4	9.3	29.3	29.6	254	259	264	243
b	24	55	328	13.7		24	250	10.4		—		—		—	
c	25	54	233	9.3		23	211	9.2		29.5		253		250	
d	22	56	171	7.8		22	162	7.4		30.0		270		214	
							Phosphorus								
3–a	21	59	249	11.9	10.3	21	274	13.0	10.6	31.7	30.8	229	255	280	245
b	23	52	284	12.3		23	282	12.3		—		—		—	
c	20	44	218	10.9		20	227	11.4		31.3		245		220	
d	25	57	158	6.3		16	92	5.8		29.4		290		234	
							Potassium								
4–a	21	47	151	7.2	6.8	21	165	7.9	8.1	28.8	29.0	275	266	180	181
b	20	50	118	5.9		19	153	8.1		—		—		—	
c	22	49	136	6.2		22	166	7.5		28.7		262		162	
d	22	43	169	7.7		22	196	8.9		29.4		260		200	

						Nitrogen and Phosphorus								
5–a	23	61	300	13.0	11.0	23	297	12.9	12.5	29.2	30.2	273	272	262	228
b	19	52	255	13.4		19	270	14.2		—		—		—	
c	20	50	207	10.4		20	266	13.3		30.3		265		276	
d	24	58	176	7.3		24	229	9.5		31.1		279		146	
						Nitrogen and Potassium								
6–a	20	43	176	8.8	8.4	20	184	9.2	9.7	28.4	28.3	237	251	170	177
b	18	39	150	8.3		18	196	10.9		—		—		—	
c	19	42	159	8.4		19	173	9.1		28.9		229		200	
d	20	44	160	8.0		20	196	9.8		27.7		288		160	
						Phosphorus and Potassium								
7–a	22	64	217	9.9	9.0+	21	285	13.6	11.0	30.7	31.0	252	250	328	282
b	21	66	232	11.0		20	253	12.7		—		—		—	
c	21	66	158	7.5		21	188	9.0		31.3		248		235	
d	19	65	146	7.7		19	168	8.8		—		—		—	
						Complete Fertilizer								
8–a	19	50	150	7.9	12.7	19	180	9.5	14.3	31.8	31.5	276	257	258	343
b	20	77	247	12.4		20	294	14.7		31.3		246		360	
c	20	76	358	17.9		20	373	18.7		31.4		248		410	
						Double Treatment, Complete Fertilizer								
9–a	21	42	145	6.9	9.9	20	163	8.2	10.6	29.3	30.1	271	260	212	251
b	20	55	265	13.3		20	268	13.4		—		—		—	
c	22	45	207	9.4		22	222	10.1		30.9		249		290	

Plats receiving no phosphorus had weights per bushel of less than 30 pounds, but in all cases where phosphorus was supplied the weight per bushel was above the 30-pound dividing line.

In size of seed, as determined by 5-gram counts, but slight difference is found. Six 5-gram samples were counted in each instance. With potash alone, with nitrogen and phosphorus together, and with no fertilizer small seeds resulted, but with potash in combination with either nitrogen or phosphorus larger seed was obtained.

The gain in yield of all phosphorus over all nitrogen plats amounts to 8 to 9% and of all phosphorus plats over all potassium plats to above 9%. Under the given conditions, phosphorus gives slightly the best results in all these methods of comparison.

TABLE 3.—*Head measurements of Lee oats (transplanted) as affected by various plant foods.*

Treatment	No. of heads	Mean length of heads in inches	Mean No. of spikelets	Correlation
None	100	10.16±.078	40.7 ±.739	+0.668±.0374
N	102	10.24±.092	39.66±.821	+0.527±.0482
P	100	9.54±.082	35.65±.700	+0.749±.0296
K	100	10.08±.080	37.9 ±.728	+0.779±.0265
NP	99	9.52±.090	35.66±.709	+0.658±.0384
NK	107	9.89±.071	39.77±.630	+0.816±.0218
PK	101	10.12±.072	39.72±.750	+0.568±.0455
2 (N P K)	116	9.83±.078	41.68±.813	+0.767±.0258

Table 3 gives additional information on the mean length of heads, the mean number of spikelets per head, and the correlation between them. Measurements were made of the lengths of approximately 100 heads in each treatment but one. The measurements vary from 9.52 inches to 10.24 inches with rather small probable errors. The number of spikelets in each head were counted and set down. The number of spikelets per head varied from 35 to 41 and the correlations between these and lengths of heads were from 0.527 to 0.816 which, by the size of the probable errors, are of considerable significance. Nitrogen gave the highest average length of heads, though the results were not entirely consistent. In number of spikelets per head no treatment (check) was second to the double complete application, while of the single elements phosphorus gave the least number of spikelets.

EFFECT OF PLANT FOODS ON FULGHUM SPRING OATS

In the field test, results of which are given in Table 2 and Table 3, the early indications were that phosphorus was an important agent in causing the early spread of the young plants. Growth was more vigorous and tillering seemingly more pronounced where phosphorus

was applied. The final results show less difference, but the early growth clearly indicated the value of phosphorus to the seedling plants. To obtain more data a similar test was planned on spring oats (Fulghum). Table 4 gives the results obtained in this test. The rod rows were hand planted with 11 to 12 grams of seed per row. Three rows of each treatment, duplicated, were included.

TABLE 4.—*Effect of various plant foods on growth and development of Fulghum spring oats, 1930.*

Treatment*	Ave. No. of heads per rod row	Ave. yields in grams per rod row	Ave. No. seeds in 5 grams (ave. of 8 tests)	Ave. weight per bushel (ave. of 8 tests)	Length of heads†	No. of spikelets†	Correlations†
None	508	285	182	31.8	4.11±.058	9.41±.224	0.485±.051
					5.66±.038	16.95±.236	0.869±.015
N	545	276	214	31.7	5.70±.042	16.83±.254	0.706±.034
					4.07±.054	8.91±.207	0.824±.022
P	489	320	181	31.3	5.72±.045	17.43±.298	0.831±.021
					4.88±.035	12.41±.195	0.749±.029
K	529	236	189	30.8	5.27±.034	13.52±.181	0.742±.030
					4.07±.047	8.82±.176	0.767±.028
N P	553	399	208	30.9	5.35±.041	15.47±.242	0.828±.022
P K	493	280	177	31.9	5.51±.040	16.83±.240	0.849±.019
					5.27±.042	14.97±.234	0.804±.023
2 (N K)	542	237	186	30.0	4.84±.042	11.19±.196	0.806±.022
					3.96±.057‡	7.95±.158‡	0.648±.039
2 (P K)	465	320	173	32.2	5.59±.044	16.49±.256	0.840±.020
2 (N)	561	395	184	33.3	5.36±.051	15.76±.325	0.801±.024
N P K	511	376	185	30.8	5.44±.038	16.57±.234	0.797±.024
					5.59±.036	17.03±.227	0.762±.028
2 (N P K)	649	491	185	33.6	5.60±.051	17.46±.323	0.451±.052
3 (N P K)	630	509	208	32.3	6.13±.056	19.98±.340	0.749±.030

*Applied at planting time in drill furrows. Equivalent to 600 pounds of 4–10–4.
†Data in the no-treatment plats are for extremes of 12 plats. Lower figures for various treatments are from the duplicated plats.
‡Single application of NK.

Double and triple applications of complete fertilizer induced the most tillering, with nitrogen alone or in combination giving the next highest number of tillers. In appearance again, the rows having phosphorus assumed an early lead and maintained it until near harvest. This advantage is reflected in the average yields per row as found in the second column. Phosphorus leads the single elements and in combinations of two, though double nitrogen and double and triple complete gave greater increases. The largest seed as indicated by smaller numbers in the counts was obtained from phosphorus and potassium, phosphorus alone being second and really no different

from the no-treatment result. In average weight per bushel, heavy applications of nitrogen and of complete fertilizer led the other treatments. In length of heads, fertilization seemed to have little effect since the heads on plants grown without fertilizer and varying from 4.1 inches to 5.66 inches in length (in averages) cover approximately the same range as those on plants grown with fertilizer. With double application of complete fertilizer, however, the average length was increased to 6.1 inches.

In number of spikelets per head, the averages show a wider range. When no plant food was applied, the range was from 9.4 to 16.95 in average number of spikelets per head; when nitrogen was used, alone or in combination, the range was from 8.9 to 20 spikelets per head. Potash gave the same range as nitrogen, but with phosphorus the range was only from 12.4 to 20, showing that this element tended to increase the number of spikelets per head, contrary to results obtained with transplanted winter oats.

Rather high and significant correlations (with a few exceptions) existed between the length of the heads and the number of spikelets per head. If all the plats receiving the various elements are considered as units, it will be found that the summary of the data is as follows:

	N	P	K
Average number of heads per row	570	541	546
Average number of grams per row	383	385	350
Average number of seeds per 5 grams	196	188	186
Average weight per bushel, pounds	31.80	31.85	31.66
Average length of heads, inches	5.20	5.51	5.21
Average number of spikelets	14.72	16.47	14.62

CONCLUSIONS AND SUMMARY

Under the given conditions phosphorus seemed most beneficial in increasing the number of tillers, the number of heads at harvest, the number of spikelets per head, the yield, and the size of the seed of oats. The results are variable and, in the matter of number of spikelets per head in winter oats, are entirely reversed.

Phosphorus exerted a marked influence in causing early tillering and growth and a quick shading of the ground. The early lead of plants having phosphorus, however, is not entirely maintained, and the difference in appearance at harvest is much less marked.

Nitrogen closely followed phosphorus in its effect upon tillering, number of heads at harvest, number of spikelets per head, and yield

Potassium exerted no influence, unless one of restriction, on number of tillers and number of heads per plant or per row at harvest,

and upon yield. In combination with nitrogen and phosphorus, however, it increased the size of seed, but the latter elements exerted better influence on the weights per bushel and upon general growth and development.

High and significant correlations were found between length of heads and number of spikelets per head in nearly all instances.

A YIELD ANALYSIS OF THREE VARIETIES OF BARLEY[1]

O. T. BONNETT AND C. M. WOODWORTH[2]

Yield is usually regarded as a complex character which is the resultant of many environmental and inherent factors acting together. Soil type, soil fertility, moisture, and temperature are important environmental factors that affect seed yield mainly by affecting plant growth. When one or more of these factors vary, differences in yield result. Similar yield differences are apparent when varieties or strains are compared under the same environmental conditions. Such differences due to strain indicate that yield is an inherited character and can be studied and dealt with as such.

In crop improvement seed yield is usually the most important of the desired characters. Selections of heads or plants are made in large numbers, and they are tested in head or plant rows. The best are continued in rod-row tests, using the grain weights of the threshed rows as evidence of superior yielding ability. There can be no question that this method has led to the discovery of improved strains. However, it does not indicate why one strain is a better yielder than another. It does not make it easier for the breeder to select high-yielding strains in the future. Farmers have been benefited by the distribution of seed of higher yielding types, but the science and methods of plant breeding have not been correspondingly advanced.

The purpose of this paper is to present the results of a study of the plant population of three varieties of barley. In this study an attempt has been made to break down the complex character seed yield into simpler components, and to determine in what components one variety is superior or inferior to another. It is an attempt to get an answer to the question, "Why is one variety a better yielder than another?"

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication December 1, 1930.

[2]First Assistant in Plant Breeding and Chief in Plant Breeding, respectively.

MATERIALS AND METHODS

Three varieties of barley, *viz.*, Wisconsin Pedigree, Velvet, and Spartan, were studied. Wisconsin Pedigree is a white, six-row, rough-awned type selected from Oderbrucker by the Wisconsin Agricultural Experiment Station. Velvet is a white, six-row, smooth-awned variety produced by the Minnesota Agricultural Experiment Station from a series of crosses involving Manchuria, Lion, and Luth as parents. Spartan is a white, two-row, smooth-awned variety produced by the Michigan Agricultural Experiment Station from a cross of Michigan Black Barbless x Michigan Two-row. These three varieties have given good yields over a period of years at Urbana, Illinois.

The plats were seeded with an 8-inch, force-feed grain drill set to seed at the rate of 2 bushels per acre. The soil was a brown silt loam of medium fertility. Each plat was approximately 1/24 of an acre in size. Two plats of the same variety were planted side by side, and the varieties were arranged in the following order: Wisconsin Pedigree, Spartan, and Velvet. The alleys between the plats were 16 inches wide. When the seedlings were through the ground, 50 1-foot sections of drill rows were staked out in each drill plat, making 100 sections for each variety. The sections were so arranged that a random sample of the area was taken and approximately the same number of sections were located on each drill row. The outside drill rows of the plat were not sampled.

At harvest the plants of each section were carefully pulled, tied together, and hung in the drying shed. When dry, the roots were carefully washed so that the plants could be easily separated. The number of one-, two-, three-, etc., to eight-headed plants was determined for each section. All plants of the same variety of the same head class, i. e., plants having the same number of heads, were bulked. The heads from the main stem, first, second, third, and so on tiller of the plants of the same head class were cut off, threshed, and weighed separately. Thus the average yield of any class of plant or tiller, as well as the yield of any foot section, could be obtained since the number of plants of the different head-classes for each section was known. Average weight per kernel was determined for each class of tiller for each class of plant in the population. One hundred kernels or a multiple was used for determining average kernel weight except where the sample did not contain as many as 100 kernels.

EXPERIMENTAL DATA

STAND VARIATIONS

A wide range of stand differences have been found by Biffin and

Engledow (2),[3] Doughty and Engledow (4), Engledow and Wadham (5), and Engledow (6, 7, 8, 9) in their investigations upon stand variations in drilled fields of wheat and barley. Engledow (6) puts his findings nicely by stating that a drilled field of grain is "simply a vast aggregate of little patches on which the plants are spaced or crowded to different degrees."

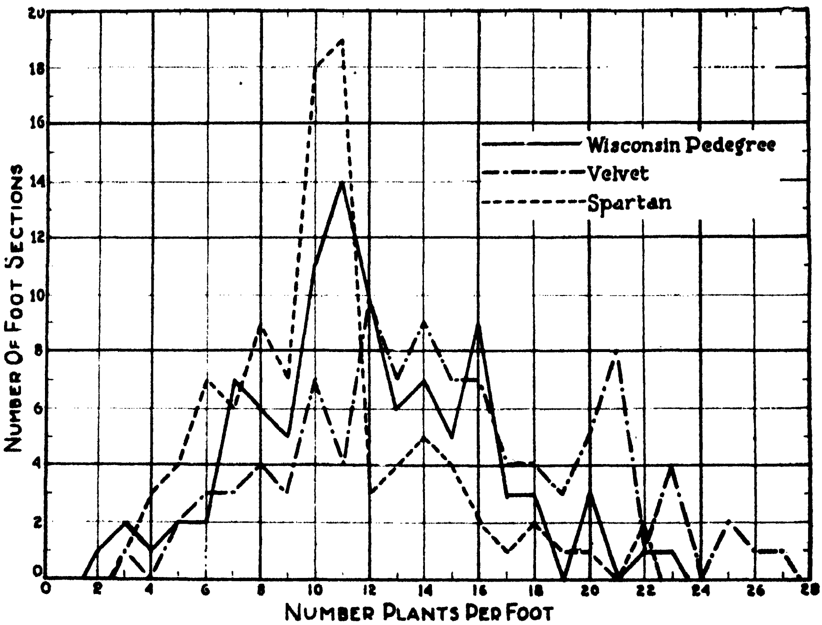


FIG. 1.—Distribution of 1-foot sections with respect to number of plants per foot section.

The wide ranges, marked irregularity, and the differences among the varieties in the number of plants per foot section are shown by the frequency polygons plotted in Fig. 1. The distribution for Spartan is positively skewed and distinctly peaked, while the distribution for Wisconsin Pedigree is more nearly normal. The distribution for Velvet, while fairly normal, is more flattened than that of Wisconsin Pedigree. The amount of variation in the distribution is further shown in Table 1 by the standard deviation and coefficient of variation, W, calculated by Weinberg's formula (19). The mean number of plants per foot is also shown for each variety. The standard deviation and the coefficient W reflect the bunching about the mean in Spartan, the more regular distribution of Wisconsin Pedigree, and the wide distribution of Velvet.

[3]Reference by number is to "Literature Cited," p. 327.

TABLE 1.—*Variation in stand as determined from 100 1-foot sections of drill row.*

Variety	Mean	S. D.	W
Spartan	10.39±.234	3.45	1.52
Wisconsin Pedigree	11.74±.282	4.17	1.88
Velvet	14.61±.366	5.43	2.17

These data bring out the marked irregularity and wide range of stands which existed in these plats. Whether such irregularity is general in all drilled fields is not known, but the studies conducted by the English investigators cited above show that there were wide ranges and marked irregularity of stand in all the drilled fields which they studied. The high variation in stand is surprising when we consider that the seeding was done with a machine in good repair and designed to give an even distribution of seed. Of course, absolute perfection cannot be realized, but it seems that a greater uniformity of seeding than was obtained should be expected.

Whether or not all of the stand variation should be charged to the drill was not determined. Engledow (9), after an intensive investigation on the action of the seed drill, stated that stand differences may be broadly attributed to (a) the drill, (b) tilth and general husbandry, (c) survival rate of seed, and (d) pests, diseases, and other damage. After an exhaustive analysis of the seeding rates on four fields of wheat, Engledow (9) stated in regard to the data, "They appear to leave no escape from the conclusion that in the operation of drilling is to be found the main cause of plant density fluctuations in typical fields of corn." It is felt that under the conditions of the present investigation, the reasons given under a, c, and d would hold, but since the plats are level and the seedbed was in excellent condition, the reason given under b would not greatly influence the stand of plants.

HEAD PRODUCTION

The average number of heads produced per plant is one of the variable plant yield characters that can be easily determined in the mature plant. While average head number does not represent the average number of tillers produced per plant, since many of the tillers do not form seed-bearing heads, it does represent the number of fruitful tillers each of which will have a direct bearing upon yield. It will be shown later that head number influences yield by affecting the number of heads per unit area, average weight of grain produced per head, and the average kernel weight.

Certain publications dealing with factors affecting tiller formation have been summarized by Engledow and Wadham (5). In the

present study, variety, size of seed, space per plant (stand), and soil fertility were the principal factors considered and these will now be discussed.

VARIETY

That varieties differ in their head production per plant has been shown by Clark (3), Engledow and Wadham (5), Grantham (10, 11), Percival (15), and Sprague (17) in studies on tillering in wheat and barley. The difference in head production of Wisconsin Pedigree, Velvet, and Spartan are clearly shown in Table 2. The range for Wisconsin Pedigree and Velvet is one to four heads per plant, while Spartan has a range of from one to eight heads per plant. The populations of Wisconsin Pedigree and Velvet are composed principally of one-headed plants having, respectively, 73.9 and 83.7% in this class, but falling off sharply in the case of the two, three, and four-headed classes. Spartan has 86.48% of its population quite evenly divided among the one-, two-, and three-headed plants, but it also falls off quite sharply in the higher head classes. However, the four- and five-headed plants together make up 11.9% of the population.

TABLE 2.—*Comparison of barley varieties in the percentage of plants bearing one, two, three, or more heads.*

Variety	Total number plants	Number heads per plant							
		1	2	3	4	5	6	7	8
Wisconsin Pedigree....	1,163	73.9	22.0	3.7	0.34	—	—	—	—
Velvet...............	1,461	83.8	12.9	3.1	0.13	—	—	—	—
Spartan..............	1,029	28.5	29.2	28.8	8.5	3.4	1.1	0.38	0.09

The difference in the head production of the three varieties is further shown when the average number of heads per plant for the

TABLE 3.—*Statistical comparison of barley varieties taken two at a time in average number of heads per plant.*

Variety	Average number heads	Diff./P.E. diff.
Spartan..............................	2.34±.0254	
Wisconsin Pedigree....................	1.30±.0110	
Difference............................	1.04±.0276	37.6
Spartan..............................	2.34±.0254	
Velvet...............................	1.19±.0082	
Difference............................	1.15±.0266	43.2
Wisconsin Pedigree....................	1.30±.0110	
Velvet...............................	1.19±.0082	
Difference............................	0.11±.0137	8.02

whole population is considered. These comparisons are brought out in Table 3. The differences between Spartan and each of the other two varieties and the difference between Wisconsin Pedigree and Velvet are significant in relation to their probable errors.

WEIGHT OF SEED

It is known that, within the same variety, plants from large seed produce a larger number of tillers than plants from small seed. Some of the literature on this subject has been reviewed by Engledow and Wadham (5). Kiesselbach and Helm (13) give some data for two winter and two spring wheats from which comparisons can be made of the percentage difference in the weight of the large and small seed, with the percentage difference in culm formation. The comparisons show that for the varieties of wheat which they studied, a relatively large difference in the weight of seed produced a rather small difference in culm formation. In the investigations cited the experiments were so planned that large and small seeds of the same variety were grown under comparable environmental conditions, and hence, any differences in culm formation could be attributed to the difference in seed size.

With the barley varieties used in this study, the situation with respect to effect of the difference in the weight of seed among the varieties upon their head production is different from the investigations cited above. The barley varieties differ not only in seed weight but there appears to be a real genetic difference in the head-producing ability of the varieties (Table 4). In each of the comparisons made in Table 4, the percentage difference in head production is greater than the percentage difference in seed weight which is the reverse of the situation for the wheats (Kiesselbach and Helm, 13). If seed size were the only factor affecting head production, it would seem that the differences in head production among the varieties would not be so great. Hence, it appears that the superiority in head production of Spartan barley over the other varieties, and of Wisconsin Pedigree over Velvet, is greater than could be accounted for on the basis of seed size alone, and therefore, it is probable that there is a real genetic difference among the varieties in head production.

TABLE 4.—*Percentage difference in seed weight and head production for the three barley varieties.*

Varieties	Percentage difference in seed weight	Percentage difference in head production
Spartan over Wisconsin Pedigree	29.6	80.0
Spartan over Velvet	40.4	96.6
Wisconsin Pedigree over Velvet	8.3	9.2

THICKNESS OF STAND

The fact that the amount of space which a plant may have influences its tillering has been brought out by Biffin and Engledow (2), Doughty and Engledow (4), Engledow and Wadham (5, 6), Engledow (7, 8), Grantham (10, 12), Kiesselbach and Sprague (14), and Percival (15). According to their findings, thick planting reduces, and thin planting increases, tillering.

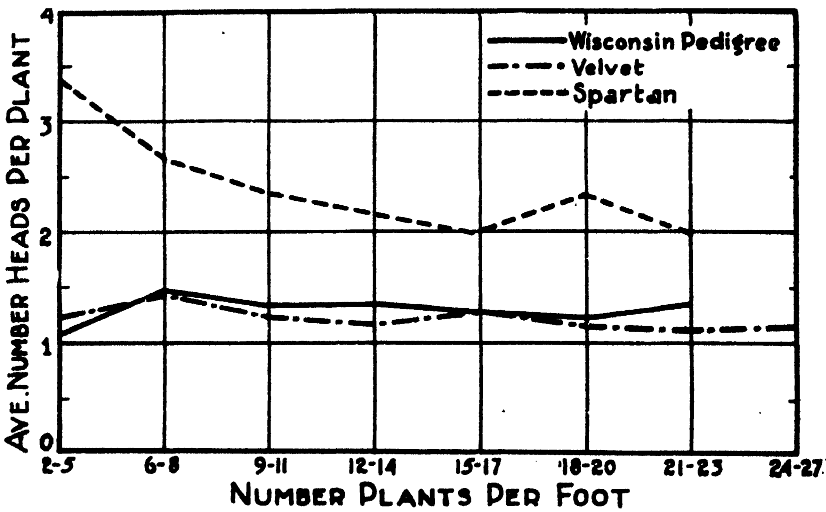


FIG. 2.—Average number of heads per plant as affected by the number of plants per foot section.

The response to space, as found in the drill plats, was different in Spartan from what it was in Wisconsin Pedigree and Velvet. This difference is shown in Fig. 2. Spartan is superior in head production to the other varieties throughout the stand range. This variety shows a decrease in the average number of heads per plant as the stand increases up to 9 to 11 plants per foot, but for thicker stands the average head number per plant remains nearly the same. The average number of heads per plant for Wisconsin Pedigree and Velvet remains nearly constant throughout the stand ranges. Wisconsin Pedigree produced a greater average number of heads per plant than Velvet for all stands except in the sections having two to five plants. The data indicate that Spartan responds more readily to variations in space than the other varieties.

If space within the sampled sections is a deciding factor in head production per plant, it should be expected that significant negative correlation coefficients would be obtained. Correlation coefficients

were calculated for the number of plants per foot and number of heads per plant. The coefficients were, for Spartan, — 0.1482 ± .0205; for Wisconsin Pedigree, 0.1183 ± .0194; and for Velvet, 0.0164 ± .0176. These coefficients are too low to indicate that any marked correlation exists, even though those for Wisconsin Pedigree and Spartan are mathematically significant, being, respectively, 6.09 and 7.24 times as large as their probable errors.

SOIL VARIATION

From frequent observations throughout the growing season no differences of any consequence could be noted in the development of the plants between the adjacent plats of the same variety. There appeared to be no fertility gradient crosswise of the plats. Therefore, it is assumed that soil variation was not a factor of major importance in accounting for the significant differences in the head production among the varieties.

In the preceding paragraphs an attempt has been made to account for the difference in the average head production per plant among the varieties on the basis of variety, seed weight, thickness of stand, and fertility of the plats. It is likely that a difference in the fertility of the plats was not an important factor. It is quite probable that a difference in size of seed and thickness of stand had some effect upon average head production per plant, but it seems that the most potent factor in accounting for the differences in the head-producing capacity of the varieties lies in the genetic differences among the varieties.

YIELD

The measurable attributes concerned with yield have been the subject of recent investigation by various workers. A literature review of the entire field will not be attempted; only a few of the recent papers which seem to have a close application to the present investigation will be cited. Biffin and Engledow (2), Doughty and Engledow (4), and Engledow and associates (5, 6, 7, 8) in England have been most active in the analysis of yield, especially of wheat and barley. In this country somewhat similar investigations have been conducted by Kiesselbach and Sprague (14), Quisenberry (16), Sprague (17), and Waldron (18) on wheat. It is shown by the authors cited that the plant attributes contributing most to yield are (a) number of plants per unit area, (b) number of heads per plant or per unit area, (c) average size of head measured either as average number of kernels or average weight of grain produced per head, and (d) average weight per kernel. The English investigators have stressed the space relationship (stand) to early plant development

and yield. American workers have considered the single culm rather than the plant as the unit.

PLANT AND HEAD NUMBER

Yield of grain per unit area can be explained on the basis of the four yield attributes mentioned. As shown above, stand and variety influence the amount of head production to different degrees. Anything which modifies the degree of head production has a direct

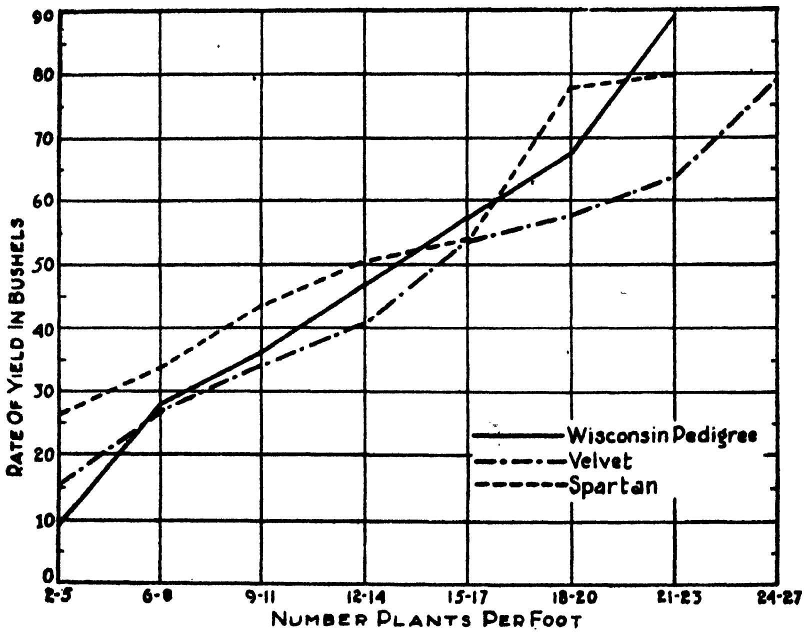


FIG. 3.—Rate of yield in bushels per acre as affected by the number of plants per foot section.

influence upon the number of heads per unit area, and hence the yield of the unit area. The close relation between yield and number of heads per unit area is shown in Figs. 3 and 4. Fig. 3 shows the rate of yield in bushels per acre for the various stands. Fig. 4 shows the average number of heads per foot for the various stands. Both head number and yield per foot increase as the number of plants per foot increases. The trends and relative positions of the lines for each variety in both figures are similar, showing the close relation between yield per foot section and head number.

The close association between head number and yield is best shown in Fig. 5. In this figure the totals for number of plants, number of heads, and yield of the respective plant classes of Spartan are plotted. The data show that the variation in yield is more closely associated

with a variation in the number of heads than with the variation in number of plants. The same is true for the other varieties, but because the number of one-, two-, and three-headed plants is nearly the same in Spartan, the relationship is more clearly illustrated by this variety.

HEAD YIELD

Yield per unit area depends not only upon the number of heads per unit area, but also upon the yield of the head as measured by the

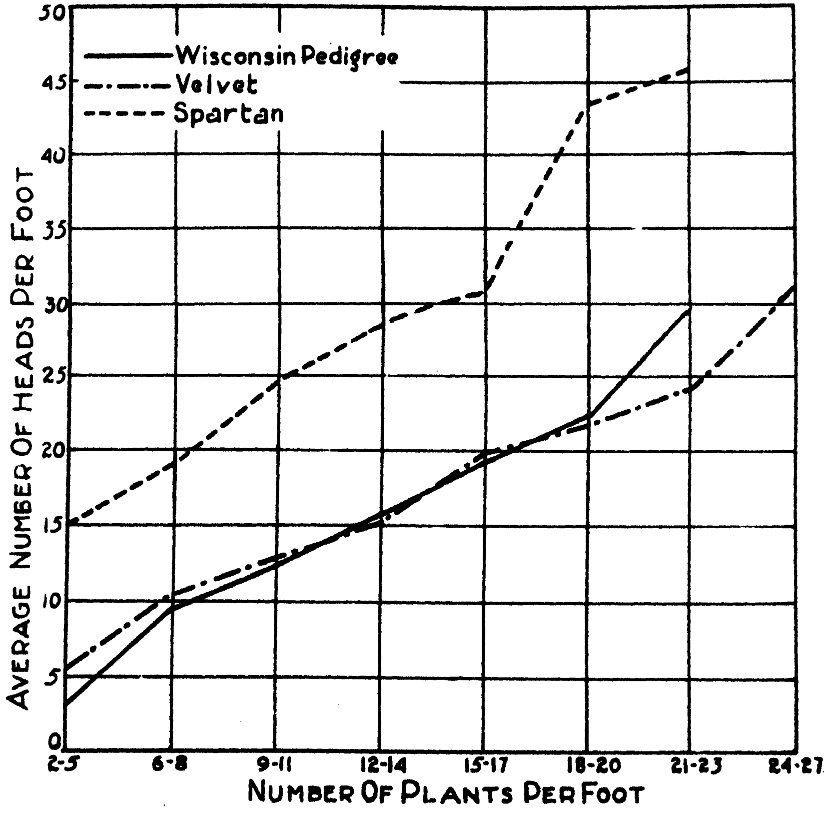


FIG. 4.—Increase in average number of heads per foot as the number of plants per foot section increases.

average weight of grain produced per head. While it has been shown (Table 3 and Figs. 2 and 4) that Spartan was significantly better in head production per plant than the other two varieties, yet its rate of yield, as illustrated in Fig. 3, was only slightly above them. Likewise, Wisconsin Pedigree, while only slightly superior to Velvet in number of heads was, except in sections having two to five plants per

foot, distinctly above Velvet in rate of yield. These differences can be accounted for on the basis of average weight of grain produced per head, which was for Spartan, 0.57; for Wisconsin Pedigree, 0.99; and for Velvet, 0.89 gram, respectively. Thus Spartan, while distinctly superior to the other varieties in head number, did not show the same relative superiority in rate of yield owing to the small yield per head, and Wisconsin Pedigree, while only slightly superior to Velvet in head number, was relatively higher in rate of yield because of its larger yield per head.

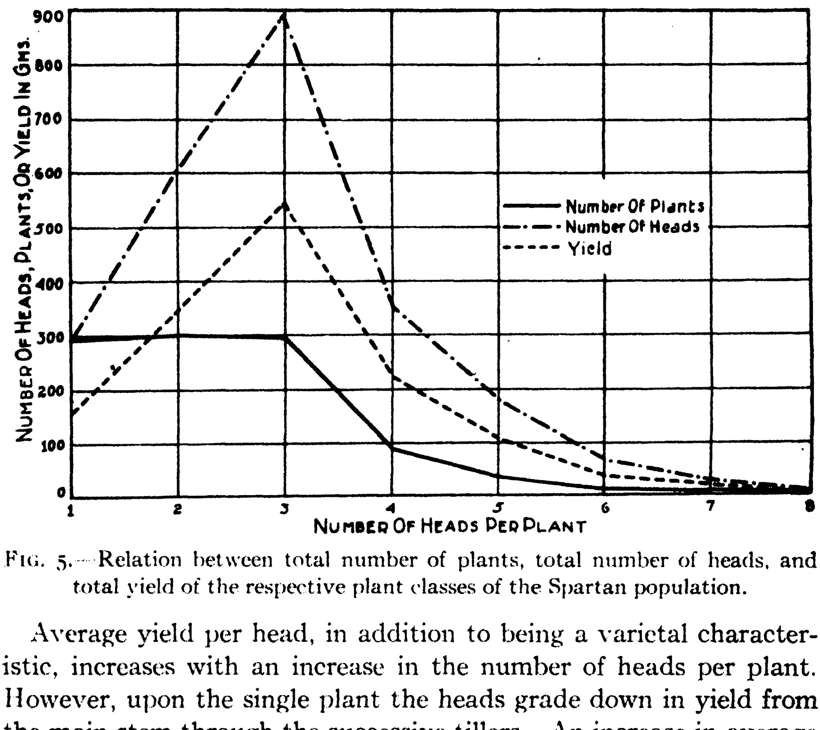


FIG. 5.—Relation between total number of plants, total number of heads, and total yield of the respective plant classes of the Spartan population.

Average yield per head, in addition to being a varietal characteristic, increases with an increase in the number of heads per plant. However, upon the single plant the heads grade down in yield from the main stem through the successive tillers. An increase in average head yield per plant with an increase in head number has been noted by Biffin and Engledow (2), Doughty and Engledow (4), Engledow and Wadham (6), and Engledow (7, 8) in their yield investigations of wheat and barley, and also by Arny and Garber (1) and Grantham (11) in their studies on wheat. Engledow (8) and Kiesselbach and Sprague (14) mention the decrease in head yield from main stem to first, second, third, etc., tiller. Thus, head yield is not only a varietal characteristic, but will vary within the variety according to the amount of tillering. Hence, there is a certain increase in yield from tillering in addition to that which would be expected from an increase in head number.

The influence of number of heads per plant upon the yield of grain per head is illustrated in Fig. 6. These data for Spartan show graphically the average yield per head for the various plant and tiller types. Two head size gradations are shown, *viz.*, a decrease in yield per head from the main head through the first, second, etc., tiller, and an in-

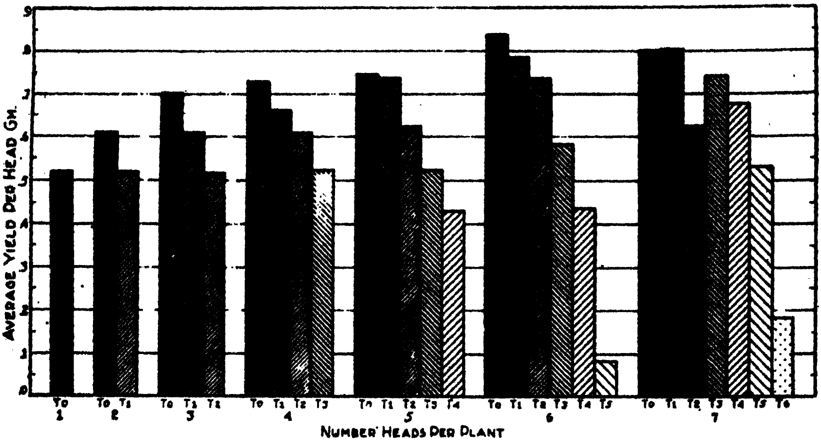


FIG. 6.—Average yield of heads produced on main stem and tillers of one- to seven-headed Spartan plants. T_0 = main stem; T_1, T_2, etc. = tillers.

crease in yield per head as the number of heads per plant increases. Up to and including the four-headed plants, the average yield of grain of the smallest head is as great as the average yield of the one-headed plants. The other heads of the plant are larger.

In the five-,six-,and seven-headed plants there were heads smaller than those of the one-headed plants. These small heads were probably borne on late tillers which, due to the shortness of the growing period, shading, and lack of available plant food, failed to

TABLE 5.—*Average yield in grams from successive heads of one-, two-, three-, and four-headed plants of Wisconsin Pedigree and Velvet.*

Class of tiller*	Number heads per plant 1	2	3	4
	Wisconsin Pedigree			
T_0	0.98	1.24	1.43	1.71
T_1	—	0.81	1.05	1.32
T_2	—	—	0.64	1.29
	Velvet			
T_0	0.85	1.20	1.18	—
T_1	—	0.73	1.08	—
T_2	—	—	0.77	—

*T_0 = main stems, T_1, T_2, etc. = tillers, according to the method of designating tillers of Engledow and Wadham (5).

attain maximum development. These data emphasize the importance of the early development of the tillers if they are to contribute much to yield of the plant.

The same relation between average head yield and head number per plant was found in the six-row varieties. Table 5 shows the same type of data for Wisconsin Pedigree and Velvet as was presented graphically for Spartan (Fig. 6).

AVERAGE KERNEL WEIGHT

The average weight of kernel is directly related to yield. The average yield per head depends upon the number of kernels per head and their average weight. If a variety with a small kernel is to have a high yielding capacity, it must have this deficiency compensated for by one or more of the other plant-yield characters. Most of the authors cited in the preceding section have noted the relation of kernel weight to yield.

Average weight per kernel is influenced by the variety. There was a distinct difference in the average kernel weight between the two types of barley. Spartan (two-rowed) and Wisconsin Pedigree and Velvet (each six-rowed) had an average kernel weight of 41.10, 31.70, and 29.27 grams per 1,000 kernels, respectively. The superiority in kernel weight of Spartan over Wisconsin Pedigree was 29.6% and over Velvet 40.4%, and of Wisconsin Pedigree over Velvet 8.3%. While probable errors could not be calculated on these data, the differences between Spartan and the other varieties are con-

TABLE 6.—*Average weight per 1000 kernels in grams from successive heads of the different plant classes.*

Class of tiller*	Number heads per plant							
	1	2	3	4	5	6	7	8
			Wisconsin Pedigree					
T_0	31.9	33.3	34.7	28.7	—	—	—	—
T_1	—	30.3	31.5	32.2	—	—	—	—
T_2	—	—	28.2	31.2	—	—	—	—
			Velvet					
T_0	28.9	30.1	32.7	—	—	—	—	—
T_1	—	29.8	31.2	—	—	—	—	—
T_2	—	—	29.5	—	—	—	—	—
			Spartan					
T_0	40.8	39.5	42.5	41.4	44.9	45.7	45.9	—
T_1	—	39.1	41.9	41.5	43.6	44.9	45.0	—
T_2	—	—	39.5	42.0	44.2	45.7	40.0	—
T_3	—	—	—	40.7	41.4	43.1	42.5	—
T_4	—	—	—	—	36.1	33.1	44.0	—
T_5	—	—	—	—	—	16.1	39.0	—
T_6	—	—	—	—	—	—	29.4	—
T_7	—	—	—	—	—	—	—	—

*T_0 = main stem, T_1, T_2, etc. = tillers.

sidered great enough to be significant, but the difference between Wisconsin Pedigree and Velvet is not.

The average weight per kernel is also influenced by the number of heads per plant and the class of head, whether produced by the main stem or first, second, etc., tiller. This is shown in Table 6. The increase in kernel weight from plant class to plant class for the several tiller classes is fairly consistent throughout. While the influence of number of heads per plant on kernel weight is not so marked as in the case of average yield per head, there is a consistent tendency for average kernel weight to increase with number of heads per plant. Thus, multi-headed plants are valuable yield units not only because the average yield per head is higher than for single-headed plants, but also because the kernels are heavier.

GENERAL FEATURES OF THE PLANT POPULATION

A summary and ranking of the three varieties with respect to the various determinations will make clear the general features of the populations. The summary and rankings are shown in Table 7. In rate of yield, total number of plants, or average number of plants per foot, Velvet ranked first, Wisconsin Pedigree second, and Spartan third. Spartan had the largest total number of heads, Velvet was second, and Wisconsin Pedigree third. For average number of heads per

TABLE 7.—*Summary and rank of the three varieties of barley with respect to yield attributes.*

Yield attributes	Values			Ranks		
	Wisconsin Pedigree	Velvet	Spartan	Wisconsin Pedigree	Velvet	Spartan
Total foot sections studied	99	100	99			
Rate of yield, bushels per acre	45.52	46.08	42.85	2	1	3
Total number of plants	1,163	1,461	1,029	2	1	3
Total number of heads	1,517	1,748	2,412	3	2	1
Average number plants per foot section	11.74	14.61	10.39	2	1	3
Average number heads per plant	1.30	1.19	2.34	2	3	1
Average yield per head, grams	0.99	0.89	0.57	1	2	3
Average yield per plant, grams	1.30	1.06	1.38	2	3	1
Average weight 1000 kernels, grams	31.70	29.97	41.10	2	3	1

plant, average yield per plant, and average weight per 1000 kernels, Spartan ranked first, Wisconsin Pedigree second, and Velvet third. In average yield per head, Wisconsin Pedigree was first, Velvet second, and Spartan third.

Genetically the plant is the ultimate yield unit. The average yield per plant is the result of a combination of average number of heads per plant and average yield per head. Average yield per head is determined by the average number of kernels per head and their average weight. Spartan ranked first in average yield per plant because it had the highest average number of heads per plant which more than compensated for the low average head yield. Wisconsin Pedigree had a higher average yield per plant than Velvet, being superior to it in all the plant-yield factors. Both Wisconsin Pedigree and Velvet had a lower average plant yield than Spartan because their greater average yield per head could not compensate for their lower average head number per plant.

Number of plants was the deciding factor in the ranking of the varieties with respect to the rate of yield. Velvet, although having the lowest average yield per plant, gave the highest rate of yield because it had the largest total number of plants in the population. Spartan had the lowest rate of yield because it had the smallest total number of plants in the population.

The danger of concluding too much with respect to the true yielding capacities of varieties from field plat tests drilled at the same rate is shown from the data presented. This is especially true when there is a marked difference in the average weight of seed as in the case of the varieties studied. Yield trials in which plant numbers, as well as other conditions are comparable, merit serious consideration, even though there are many difficulties involved in conducting tests on this basis. For example, if Spartan and Wisconsin Pedigree had had the same number of plants as Velvet and had the average plant yield remained the same, the yielding rate would have been approximately Spartan 60.5, Wisconsin Pedigree 57.0, and Velvet 46.0 bushels per acre. It is evident, therefore, that under ordinary conditions one variety may be favored and another handicapped due to rate of seeding.

The plant yield factors which contribute to the yielding capacity of a particular variety can only be determined by a study of the individual plants. Such an analysis brings out the relation between the various measurable plant yield factors in their influence upon yield per plant or yield per unit area, and also shows how varieties under field conditions differ with respect to the various plant-yield factors. Specific information relative to the particular yield characteristics of

each variety is obtained which is of value to the plant breeder in selecting varieties for crossing in an attempt to combine all of the desirable plant-yield factors.

SUMMARY

1. A yield analysis of three varieties of barley, *viz.*, Wisconsin Pedigree, Velvet, and Spartan, growing in drill plats, was made by taking plants from 50 1-foot sections of drill row located at random from each of two plats of a variety. The plats were approximately 1/24 of an acre in size. The data were reduced to a plant basis.

2. The stands within the sampled sections ranged from 2 to 27 plants per foot. Variation in stand was probably due primarily to the unequal distribution of seed by the drill in addition to other causes which affect seedling survival.

3. Spartan produced an average of 2.34; Wisconsin Pedigree, 1.30; and Velvet, 1.19 heads per plant. This significant varietal difference in average head production per plant was considered to be inherent. Variation in soil fertility was probably not a serious factor, while differences in size of seed and thickness of stand had only slight effect.

4. The rate of yield in bushels per acre was Velvet, 46.08; Wisconsin Pedigree, 45.52; and Spartan, 42.85. Yield per unit area was more closely associated with the number of heads than with the number of plants per unit area. Average yield per plant depended upon the average number of heads per plant and the average weight of grain produced per head.

5. Average yield of grain per head was Wisconsin Pedigree, 0.99 gram; Velvet, 0.89 gram; and Spartan, 0.57 gram. Average weight of grain produced per head varied with the variety, number of heads per plant, class of tiller, and average kernel weight.

6. In total yield for the entire area studied, Velvet was first, Wisconsin Pedigree second, and Spartan third. The order was the same for total number of plants. Spartan, while superior to the other varieties in average yield per plant, had a smaller rate of yield because of a smaller total number of plants, and for the same reason Wisconsin Pedigree yielded less than Velvet.

7. The yield characteristics of a variety can best be determined by a study of single plants. Information derived from such a study is of value to the plant breeder in choosing varieties for crossing in an attempt to combine all of the desirable plant-yield characters. The analysis showed that if seeded at the same rate (pounds per acre) a small-seeded variety may outyield a large-seeded variety on account of the larger number of plants per unit area rather than because of superior plant-yield characters.

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NOTE

NEW RUSSIAN WHEATS WHICH WILL NOT SHELL OR SHATTER EASILY

In connection with the development of large scale production of wheat on the Soviet-owned farms (sovkhozi), the question of selecting varieties which will not shell out or shatter becomes of great importance. Consequently, during the past year, one of the experiment stations in the western part of Siberia has been conducting experiments with various varieties of wheat, particularly as to the percentage of shelling.

It is interesting to learn that while some varieties have shattered or shelled as much as 19.6%, other varieties have shattered only 2 to 3%. An effort is now being made to discard all the high-shelling varieties and adopt those which show low shelling.

Among these, the following Russian varieties Blansar, Sarrosa, and Sarrubra, developed by the Satatov Experiment Station, have shown the lowest percentage of shelling. "Aone", the American variety Kubanka, has also shown a low percentage of shattering.

During 1931, the tests will be continued and, in addition to the Russian varieties, several American varieties will be introduced—J. W. PINCUS, *New York City*.

BOOK REVIEWS

SOIL MANAGEMENT

By Firman E. Bear. New York: John Wiley & Sons Inc. V + 412 pages, illus. Ed. 2, second printing corrected. 1931. $3.50.

This is the second printing of the second edition of this valuable text, originally printed in 1927.

A superficial examination of the new printing would show no changes, as the material is divided into the same five general divisions, with identical chapter headings and almost identical paging. Critical examination, however, shows that a few minor changes have been made in order to bring some parts of the text up to date. Thus, fertilizer production and consumption data have been revised and new changes in terminology incorporated. Recent experimental results touching several subjects in the text have been added, notably in connection with nitrogen carriers, fertilizer formulas and ratios, and fertilizer practice. Otherwise the book is identical with the original second edition. (R. C. C.)

BIBLIOGRAPHIES ON GENETICS AND BREEDING OF CORN AND COTTON

By C. K. McClelland. Fayetteville, Ark.: Published by the Author. Combined references, $1.00; corn alone, 75 cents; cotton alone, 60 cents; postpaid. 1931.

Effort has been made to include all important articles (period 1889–1929) concerned with the genetical, cytological, botanical, and statistical phases of the improvement of these crops. An index of authors facilitates the finding of any known reference. Many articles from other countries than the United States are listed. References to

abstracts in *Experiment Station Record*, *Botanical Abstracts*, and *Biological Abstracts* (for most of the articles) are a unique feature of the work, which in the combined form contains 1,300 references.

To students and teachers of genetics and plant breeding, as well as to research workers with these crops, these bibliographies will be invaluable. (O. A. P.)

AGRONOMIC AFFAIRS

THE ANNUAL MEETING OF THE SOCIETY

The twenty-fourth annual meeting of the American Society of Agronomy will be held November 19 and 20 at the Stevens Hotel in Chicago. Announcement of the meeting is made at this early date in order to bring to the attention of members of the Society a new plan to be tried out this year whereby printed abstracts of all papers to be presented at the meeting will be made available in advance of the meeting.

Four symposia are to be arranged, as follows: Cold and Drought Resistance in Plants, R. I. Throckmorton in charge; Soil Organic Matter and Soil Classification, S. A. Waksman in charge; The Relation of Calcium and Magnesium Compounds to Soil Conditions and Plant Growth, A. B. Bueamont in charge; and Soybeans, W. J. Morse in charge.

The Friday afternoon session will be open to the presentation of papers submitted by members of the Society. Any member of the Society may present a paper at that time, providing the title is sent to the Secretary not later than October 1, together with a statement of the time required to present the paper and an abstract of not more than 200 words.

SUMMER MEETING OF THE NORTHEASTERN SECTION

A summer meeting of the newly organized Northeastern Section of the Society is to be held at Pennsylvania State College in June at the time of the celebration of the 50th anniversary of the establishment of the soil fertility plats at State College. The time and place for the first regular meeting of the new section will be decided upon at the Pennsylvania meeting.

The Executive Committee of the Section has named the following sub-committees to assist in the coordination of research on projects outlined by the association of northeastern states experiment station directors: *Pasture Investigations*, B. A. Brown, *Chairman*, W. H. Pierre, and F. D. Gardner; *Soil Organic Matter*, S. A. Waksman, *Chairman*, B. D. Wilson, and M. F. Morgan; and *Fertilizer Ratios*, A. B. Beaumont, *Chairman*, J. A. Chucka, and G. L. Schuster.

COTTON ROOT-ROT CONFERENCE

Thirty-four agronomists, soil chemists, plant pathologists, botanists, and horticulturists from the United States Department of Agriculture and the Texas Agricultural Experiment Station engaged in a cooperative study of the cotton root-rot disease attended the fourth annual conference on root-rot held at College Station, Texas, January 19 and

20, 1931. This annual meeting furnishes an opportunity for all the agencies studying root-rot to get together and discuss the results obtained and to discuss plans for the future study of the problem. Forty-six papers, dealing with the life history and nutrition of the fungus and methods of control, were presented at the meeting.

THE SPRAGG MEMORIAL LECTURES

Dr. T. A. Kiesselbach, of the University of Nebraska, gave the second series of annual lectures under the Frank Azor Spragg Memorial Fund, March 10 to 13, 1931, at Michigan State College. This memorial is in honor of Professor F. A. Spragg who was in charge of plant breeding work at the Michigan Agricultural Experiment Station from 1906 until his death in 1924. The subjects dealt with in the lectures were as follows: The Morphology of the Corn Plant (Illustrated); The Technic of Field Experiments; New Crops for Old; The Present Status of Hybrid Corn; and the Use of Control Measures and Equipment in Crop Improvement.

NEWS ITEMS

ORVILLE VOGEL, who completed work for his master's degree in the Department of Agronomy, University of Nebraska in January 1931, has accepted a position with the Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture. He will be stationed at Pullman, Washington.

T. H. GOODDING, Associate Professor of Agronomy at the University of Nebraska, left February 1 on sabbatical leave to take work on a doctorate degree at Cornell University.

P. J. OLSON, in charge of the corn breeding work at North Dakota Agricultural Experiment Station at Fargo, is on sabbatical leave to continue studies toward a doctorate degree at the University of Nebraska. His leave became effective February 1.

CALEB JORGENSEN, 1930 graduate of University of Nebraska, has been appointed to a fellowship in the Department of Agronomy, Kansas State Agricultural College, effective February 1. Mr. Jorgensen will receive his master's degree.

HENRY BEACHELL, graduate of the University of Nebraska, and who has been doing graduate work toward has master's degree at the Kansas State Agricultural College during the past year, has accepted a position with the Office of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Mr. Beachell will conduct rice investigations at Beaumont, Texas.

L. D. BAVER, formerly Assistant Soil Chemist of the Alabama Agricultural Experiment Station, has been appointed Assistant Professor of Soils, University of Missouri, Columbia, Mo.

W. S. EISENMENGER has been appointed research Professor of Agronomy in the Massachusetts Experiment Station in the place of Dr. J. P. Jones, now with the Koppers Research Corporation, Ligonier, Pennsylvania.

FRANK K. HOOVER, who, among other interests, was a director in the Ruhm Phosphate and Chemical Company, died at his home in Chicago on March 6.

DR. L. H. PAMMEL, professor of botany at Iowa State College and for several years a member of the Society, died on March 23 while returning home from a winter in California.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 MAY, 1931 NO. 5

THE BASE EXCHANGE PROPERTIES OF SOIL ORGANIC MATTER[1]

W. T. McGEORGE[2]

In searching the literature for references on the exchange capacity of organic matter in soils, it has been found that little exact information is available, while studies on the base exchange properties of the inorganic fraction are legion. In spite of this, it has been the custom in referring to the exchange property of soils to speak of the zeolite-humate complex. Recognizing a demand for a better knowledge of this property in the organic fraction, as well as a need for quantitative data and a knowledge of the nature of the materials involved, a set of soils was assembled suitable for such an investigation. A study of these soils has yielded much of interest and value.

Reviewing briefly previously published work (3)[3] on this problem, it was first sought to establish definitely the validity of several assumptions regarding the exchange properties of the so-called soil humate. The first question was the chemical equivalency of the exchange reaction. The data answered this in the affirmative. That is, the base exchange reaction takes place, in the organic fraction of the soil, in chemically equivalent proportions.

Second, since H_2O_2 had been used as a reagent for destroying organic matter in soils, and thereby the exchange capacity as measured by the loss in absorption, we were interested also in the effect of this active oxidizing agent upon the inorganic exchange

[1]Contribution from the Department of Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Arizona. Presented as part of a symposium on "The Nature of Soil Organic Matter and Its Relation to Soil Fertility" held at the annual meeting of the Society, Washington, D. C., November 21, 1930. Received for publication December 1, 1930.

[2]Research Chemist in Soils.

[3]Reference by number is to "Literature Cited," p. 336.

complex. It is significant that considerable silica and alumina are dissolved from soils by the H_2O_2 treatment. This led us to suspect a decomposition of zeolites as well as organic matter. To state the findings briefly it will suffice to say that, using a number of natural and synthetic inorganic exchange compounds, the exchange capacities of the natural bentonites were found to be unaffected by digestion with H_2O_2, while those of the synthetic materials were only slightly reduced. On the basis of these observations, the H_2O_2 method was then applied to a set of 20 soils and a linear relationship was found between the loss in replacement capacity and the carbon lost by the soil during digestion with H_2O_2. This reagent may therefore be used in a difference method for determining the exchange capacity of soil organic matter.

The third question involved the nature of the organic compounds which function in base exchange reactions. Having a wide variation in soil types among those under study, with a C content ranging from 0.5 to 56.05% and a N variation of 0.073 to 3.23%, our curiosity was aroused as to the relationship existing between these two elements in the organic fraction and the replacement capacity. On plotting the percentage of C against replacement capacity, it was found that the relationship was quite closely that of a linear function. On the other hand, there appeared to be no relationship whatever between N, or the C-N ratio, and replacement capacity. The logical interpretation of the above is that the C compounds, other than the highly nitrogenous materials, function as the base exchange compounds. Now the most abundant soil organic compounds which fall in the above classification are lignin, hemicellulose, and cellulose, and for only short periods of time, the more reactive carbohydrates. Of these, lignin appeared to be the most likely compound. This material represents one of the major constituents of soil organic matter. Then again, among the organic compounds of the soil, it is one of the most resistant to the destructive chemical and biological reactions.

In the separation and preparation of the lignin complex of soils, several methods were used. The universal solvent for the so-called soil humate is NaOH, either as an alcoholic or aqueous solution. The alcoholic solution is more selective than the aqueous solution and from it fairly pure lignin may be precipitated by means of acids. On the other hand, by the same process, using an aqueous NaOH solution, a more complex material which includes hemicellulose as well as lignin is obtained. Materials prepared by these two methods will be referred to for convenience as lignin in the former case and

ligno-humate in the latter. In addition, we were fortunate in obtaining from Dr. Phillips of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, a small quantity of corn-cob lignin.

The base exchange properties of these three materials were rather carefully studied, using neutral solutions of the salts of divalent bases. All showed base exchange reactions in chemically equivalent proportions. The quantity factor was variable. For example, lignin and ligno-humate were prepared from 10 different soils. The exchange capacity of lignin varied in different samples from 38 M. E. to 178 M. E. per 100 grams, while the capacity of ligno-humate varied from 327 M. E. to 420 M. E. Corn-cob lignin showed an exchange capacity of 36 M. E., while a sample of lignin which was prepared from alfalfa showed an exchange capacity of 100 M. E.

The literature shows that lignin is a variable compound. In fact the composition may not even agree if isolated from different parts of the same plant. One important variation is in the number of hydroxyl and methoxyl groups present in the molecule. Whether such a variation can be associated with the wide range in exchange capacity of lignin from different soils cannot be stated at this time. The most significant feature of the above data is the high exchange capacity of the ligno-humate. Knowing that aqueous NaOH extracts hemicellulose in addition to lignin, this material was studied as represented by xylan. A small exchange capacity was found, *viz.*, 11 M. E. per 100 grams, for xylan which was prepared from wheat straw. This capacity falls far short of accounting for the greater capacity of the ligno-humate as compared to lignin.

Pursuing a different line of attack, it was found that if lignin is leached with dilute HCl a great increase in exchange capacity will follow, probably through hydrolysis. This change in capacity was more characterized in the lignin than in the ligno-humate. The capacity of one sample of soil lignin was changed from 92 M. E. to 213 M. E., or an increase of 121 M. E. By the same treatment corn-cob lignin was increased from 36 M. E. to 166 M. E., or 130 M. E. On the other hand, the greatest increase noted for any sample of ligno-humate was 56 M. E.

Several extractions were conducted by heating the soil with aqueous NaOH at 10 pounds steam pressure. While this method extracted a greater amount of ligno-humate, the exchange capacity is not different from the ligno-humate dissolved by aqueous NaOH at atmospheric temperature and pressure. These observations suggested the following: (a) Lignin exists in soils not alone as such, but also as complex compounds insoluble in alcoholic NaOH, but soluble or broken down

into component parts (one of which is lignin) by aqueous NaOH; and (b) by a reaction with aqueous HCl (probably hydrolysis) the solubility of lignin-like bodies is increased.

To account for the greater exchange capacity of ligno-humate as compared to lignin, all the evidence indicates that the exchange capacity of lignin increases as the organic fraction of the soil passes through successive stages of decomposition. The lower-capacity lignin represents the less altered form, as for example, the 36 M. E. capacity for corn-cob lignin contrasted with a range of 38 to 178 M. E. for the lignins from 10 different soils.

In connection with the above, it may be of interest to state that the lignin, hemicellulose, and cellulose in a selected group of soils were determined quantitatively and a linear relationship found between the percentage of lignin and the replacement capacity. There was no relationship between the percentage of cellulose or hemicellulose and replacement capacity.

Regarding the chemical properties of the lignates and ligno-humates, a striking similarity to the inorganic zeolites was found, and some rather extensive experiments have been conducted upon their ionization, hydrolysis, the effect of a common ion on replacement, dye absorption, and their reaction toward solutions of Al salts.

It was found that on leaching a lignate with a solution of $AlCl_3$ there was a partial loss or "breakdown" in replacement capacity which could be restored by subsequently treating with an acetate or hydrate of a divalent base. At the same time there was no absorption of Al ions by the lignate. This is also a characteristic property of the inorganic soil zeolites (2).

The lignates exhibit the properties of ionization and hydrolysis in a manner somewhat similar to the zeolites. The tendency to hydrolyze is in the order Na $>$K $>$Mg $>$Ca $>$Ba, just as in the zeolites, while the same relative order of ionization was found. Ionization of the H-saturated lignate is approximately equal to the Ca salt, both being very low. While hydrolysis is most active in the Na and K lignates, the Mg salt hydrolyses sufficiently to show a color and appreciable solubility on leaching with water.

It is well known that the ionization and hydrolysis of a zeolite may be completely stopped by the presence of a common ion in sufficient concentration. Studies of this nature have been conducted with the lignates. While space will not permit a detailed discussion, the following simple experiment will serve to illustrate this property. If, to a solution of Na lignate, alkaline to phenolphthalein, an excess of NaCl is added, hydrolysis will be forced back and the pink color will completely fade from the solution.

Another similarity was noted in the absorption of dyes. Lignates were found to absorb basic fuchsin in such a form that it was replaceable by the base of a neutral salt solution. This, too, is a characteristic property of zeolites.

Synthetic humates have often been used in connection with studies on the natural soil humates. In view of this fact, such materials have also been included in the investigations. The usual method of preparing these synthetic products is to digest a carbohydrate on the hot water bath with dilute HCl until the whole becomes a black mass. Using such a method for sucrose, xylan, and cellulose, synthetic humates were obtained in every case which possessed the property of base exchange in chemically equivalent proportions.

Beckley (1) has shown that carbohydrates may yield furfuraldehyde or methyl-hydroxy-furfuraldehyde by such reaction, and Schrauth (5) has shown that there may be a formation of a fundamental unit of the lignin molecule by condensation of three molecules of methyl-hydroxy-furfuraldehyde. There is, therefore, some basis for a belief that a similarity may exist between the synthetic and natural humates.

Throughout the investigations we became more and more convinced that, since lignin and lignin-like bodies are present in practically all plants, raw plant material should possess the property of base exchange in its natural state and before its incorporation with the soil. To test out this theory alfalfa, the principal soil-building crop of the Southwest, was selected and it was found that this surmise was correct. In other words, an exchange capacity of chemically equivalent proportions for ground alfalfa (no roots) of 58 M. E. per 100 grams was found, and furthermore, it was found that upon extracting this material with alcoholic and aqueous NaOH it yielded a lignin of 100 M. E. replacement capacity and a ligno-humate of 107 M. E. replacement capacity. Attention is called to the lower replacement capacity of ligno-humate from unaltered or undecomposed organic matter as compared to that of soil. This will illustrate the point which we have already emphasized regarding the increase in replacement capacity which appears to accompany the successive stages of decomposition in the soil.

We were surprised to learn on digesting the raw plant material (alfalfa) with H_2O_2 that a large part of the exchange capacity was not destroyed. While there is always present in plants appreciable amounts of the inorganic elements, such as Si, Al, and the bases which go to make up the zeolite molecule, no one, so far as we know, has ventured the suggestion that they may be combined in plants to

form zeolite-like compounds. Yet, in view of the work of Robinson (4) and others in which the completeness of the destructive reaction of H_2O_2 on organic matter has been demonstrated, we were led to suspect this. However, being unable to conceive of such a small amount of inorganic matter as is present in alfalfa being responsible for such a high exchange capacity, the point was investigated further.

The original alfalfa contained 38.7% C. This was reduced to 32.8% by leaching the ground alfalfa with hot water, to 21.6% by digestion with H_2O_2, and to 17.7% by subjecting the sample to a second digestion with H_2O_2. By using soil as a catalyst the C was reduced to 9.6% by digestion with H_2O_2. From this it was concluded that H_2O_2 had only partially destroyed the lignin compounds and thus only partially reduced the organic exchange capacity. It is apparant that "raw" organic matter is not easily decomposed by H_2O_2. If this reagent is to be used in a difference method for determining the organic exchange capacity of soils, then it is necessary that a C determination be made upon the residue.

SUMMARY

In the preceding discussion of the base exchange property of organic matter in soils, many phases of the problem as studied have been treated but briefly owing to limited space and to a desire to present as many observations as possible. In summarizing, the following should be emphasized especially: (a) The definite relationship existing between the organic C content of soils and their exchange capacities; (b) the value of H_2O_2 in determining quantitatively the organic exchange capacities of soils; (c) the exchange property of lignin and lignin-like bodies; (d) the similarity in chemical properties of the basic and acid salts of lignates and zeolites, such as hydrolysis, ionization, and the common-ion effect; and (e) the exchange capacity of unchanged plant materials which possibly leads us into a field slightly foreign to soil study. It is felt that the exchange property of green manures is one of considerable economic importance to agronomic practice and one which has been largely overlooked.

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HOW RELIABLE ARE EXISTING CHEMICAL METHODS FOR DETERMINING SOIL DEFICIENCIES IN ASH CONSTITUENTS OF PLANTS?[1]

G. S. FRAPS[2]

The relation of the chemical composition of the soil to soil fertility is a fundamental and difficult problem of agricultural chemistry. Soil fertility is the resultant of many factors; its relations are influenced not only by the quantity of the various compounds present, and they by one another, but also by other conditions, such as the physical character and condition of the soil, and other variables, such as moisture, temperature, and bacterial action. Field results as measured by yields are influenced by the factors just mentioned and others in addition, such as the depth of the surface soil, the depth of subsoil, and variations in the physical character of the soil. Many areas are so variable and so difficult to sample that the samples taken may not represent the field being studied.

The potential fertility of the soil, as such, must be distinguished from the productiveness of the soil as measured by crop yields. The soil may, for example, have a high capacity to supply potash to plants, varying, to some extent according to the nature of the plant. The crop grown, however, may not be able to take up the potash, owing to the adverse operation of other factors, or, having taken it up, may not be able to effect a corresponding production of grain or other crops. What applies to potash applies also to phosphoric acid, nitrogen, and other factors of fertility. The power of the soil to supply one or more of them is not necessarily reflected in the yield of the crop. The ability of the soil to supply, and the power of the crop to use, are two separate things, and must be considered separately.

The chemical analysis of a sample of soil shows the quantities of nitrogen, phosphoric acid, potash, or other constituent which may be estimated by the particular method employed. For the interpretation of the analysis, the relation must be traced between the results of the analysis and the production in the field which the sample is supposed to represent, and the conclusions expressed in terms of soil fertility, or soil deficiency, or the need for some particular fertilizer or

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Published as Technical Contribution No. 134 from the Texas Experiment Station. Also presented at the symposium on "Diagnosing Soil Deficiencies and Crop Needs" at the meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication December 5, 1930.

[2]Chief of Division.

amendment. The chemical composition of a soil is most closely related to the potential fertility of the soil or what may be termed the capacity of the soil to furnish plant food. The capacity to furnish plant food is thus a characteristic of the soil itself, apart from the need of the plant, or the power of the plant to take food, which are characteristics of plants, and apart from depth, structure, climate, or season, which are characteristics of the soil type or its environment. The extent to which the capacity of the soil to furnish plant food is effective in the field is profoundly influenced by the crop grown, the characteristics of the soil type, and environmental conditions. The chemical analysis can measure only the capacity of the soil to furnish plant food. In the interpretation of the results, the other factors must be considered or allowed for. It is of course exceedingly difficult to evaluate all the factors which influence soil fertility, but the more accurately all are allowed for, the more nearly correct will be the interpretation of the results of the analysis.

PROPOSED CHEMICAL METHODS

PHOSPHORIC ACID

The most popular method in Germany and other parts of Europe at the present time for the determination of phosphoric acid involves the use of 1% citric acid. It has been given extensive study abroad and has been used in thousands of tests for deficiency of phosphoric acid in field soils. This method was first proposed by Dyer (5),[3] who by means of it traced relations between the analysis and the field results at the Rothamsted Experiment Station (6). The method was also studied by various referees (2) of the Association of Official Agricultural Chemists, but 0.2N hydrochloric acid was accepted (1) for a time, and 0.2N nitric acid seemed to be preferred at the time the work was discontinued. The method has recently been described fully by Lemmermann (20) and by Koenig and Hasenbaumer (19).

Another important method for phosphoric acid involves the use of 0.2N nitric acid, the results being termed the active phosphoric acid or active potash. Some referees of the A. O. A. C. found that the 0.2N hydrochloric or nitric acid gave practically the same results as 1% citric acid, but was much more easily handled from an analytical standpoint. Hydrochloric acid, 0.2N, was for a time adopted by the A. O. A. C. (1).

Among other solvents proposed to extract the so-called available phosphoric acid are 0.005N hydrochloric acid (23), 0.1N nitric acid,

[3]Reference by number is to "Literature Cited," p. 350.

0.002N sulfuric acid (26), and 1% potassium carbonate (4) for calcareous soils. The 0.005N hydrochloric acid was found by some (24) not so good as the stronger hydrochloric acid or nitric acid.

It is probable that any dilute mineral acids and many organic acids would dissolve phosphoric acid in some relation to the capacity of the soil to furnish it, so that there are wide possibilities for proposing new methods which are slight modifications of the older ones. Any proposed new method, to justify serious consideration, should be accompanied by extensive data to prove decisively that it gives results more closely related to the capacity of the soil to furnish plant food than those secured by the older method. Unless some improvement can be given, any new method merely seems to divert energy from the main issue. Rapid field methods have been proposed by Bray (3), Spurway (25), and others. Such a method is desirable. It should be linked up with other work.

The estimation of total phosphoric acid has not been seriously proposed for estimating the immediate deficiencies of soils in phosphoric acid, though Lemmermann uses it in connection with the phosphoric acid soluble in 1% citric acid, and Hilgard used it for judging the durability or wearing quality of the soil. The estimation of water-soluble phosphoric acid is usually considered a means of research rather than a method of ascertaining the deficiency of a soil in phosphoric acid, since mineral phosphates have a very low solubility in water.

POTASH

For potash, as for phosphoric acid, the solvents used more extensively are 1% citric acid (European) and 0.2N nitric acid (American). The method using 0.2N nitric acid (active potash) was developed by the A. O. A. C. (2). The replaceable potash (17) has been studied, but has been used only to a very limited extent in judging the deficiencies of the soil. The 1% citric acid and 0.2N nitric acid take out part, but not all, of the replaceable potash. Extensive analyses have been made for total potash and for water-soluble potash, but little attempt has been made to use them for ascertaining deficiencies of field soils in potash.

NITROGEN

Chemical methods have been used to a very small extent by European scientists to judge soil deficiencies in nitrogen. Some of them claim that almost any soil will respond to nitrogen under favorable conditions. Koenig and Hasenbaumer (19) propose the use of a 1% solution of potassium sulfate to estimate the easily soluble nitrogen

of the soil, and claim that the method is of practical value. The total nitrogen of the soil and also the nitrates produced under uniform conditions are related to the capacity of the soil to furnish nitrogen in pot experiments, as will be shown later.

RELATION OF CHEMICAL ANALYSIS TO POT EXPERIMENTS

The relation between the chemical composition of the soil and its capacity to furnish plant food is best studied by comparing results of pot experiments with results of the chemical analyses. In pot experiments, the soil can be mixed and made uniform, samples can be taken which represent accurately the chemical composition of the soil under experiment, and the experiments can be conducted in such a way that many variables which affect field results are reduced or even entirely eliminated.

Since the object of the experiment is to ascertain the capacity of the soil to furnish the particular element being studied, it is necessary to make analyses of the crops and calculate the amounts of plant food withdrawn, instead of using the green or dry weight of the crop. The fact that the percentage of plant food in the crop varies considerably is another good reason for the analyses. When an abundance of potash is present, plants may contain high percentages of potash.

Plant food other than the element studied should be added, so that the amount of this element taken up by plants cannot be restricted by deficiency of other elements.

It is reasonable to assume that methods of analysis which give the closest relations to the results of the pot experiments would also have the closest relation to the capacity of the soil to furnish plant food and to possible deficiency in the field. Extensive data are needed in tracing these relations, as other factors are present which may obscure the main relations.

PHOSPHORIC ACID

Extensive comparisons of chemical analyses with pot experiments have been made at the Texas Agricultural Experiment Station. Phosphoric acid, nitrogen, and potash were studied. In studying phosphoric acid, the test pots of 5,000 grams of soil each received potash and nitrogen, while the check pots received phosphoric acid, potash, and nitrogen. The quantity of phosphoric acid removed by the crop from the soil which did not receive phosphoric acid was taken to be the measure of the capacity of the soil to supply phosphoric acid. This is considered to be a better measure than the

dry weight of the crops, either relative to the check pot or on an absolute scale. It is understood that variations in size of pots, weight of soil, crop grown, temperature, and other conditions might affect the quantities of phosphoric acid removed by the crop. These were maintained as nearly constant as possible. The relation between the active phosphoric acid of the soil, or that removed by 0.2N nitric acid (8, 14), and the phosphoric acid removed by plants, in some of the many sets of pot experiments reported (14), is shown in Table 1. As is seen, there is a close average relation. Soils low in active phosphoric acid are also low in their capacity to supply phosphoric acid to plants in pot experiments. There is more variation and more uncertainty with respect to soils high in active phosphoric acid.

TABLE 1.—*Relation of the active phosphoric acid of the soil to the phosphoric acid removed by cropping in p.p.m. of the soil.*

Group No.	Number of soils	Active phosphoric acid in soils	Phosphoric acid in average of 4 crops
Series 131, 29	18	7.3	2.7
Series 4, 14, 30, 47	44	14.8	4.5
Series 36	9	25.1	5.6
Series 28	8	34.8	12.8
Series 17 and 27	16	48.3	8.2

The correlation coefficient was found to be .57 ± .05 for the active phosphoric acid and .45 ± .06 for the total phosphoric acid in these experiments.

It must be remembered (8) that the dilute acid may dissolve different kinds of phosphates from soils of varying origin or fertilization, that soils can absorb or fix part of the phosphoric acid dissolved, that plants vary in their power to take up phosphates, and that the phosphates may be covered or encrusted by materials soluble in acids but not penetrated by plant roots. In view of these considerations, a very high degree of relation cannot reasonably be expected between the chemical analysis and the capacity of the soil to furnish phosphoric acid to the plants. A reasonable and useful relation is found.

POTASH

At the Texas Agricultural Experiment Station (10, 11, 16, 17) comparisons similar to those outlined above for phosphoric acid were made between the capacity of the soil to supply potash in pot experiments and the chemical composition of the soil. A comparison

of the active potash with the results of some pot experiments is given (16) in Table 2. Here the results are more closely related than those secured with the phosphoric acid. The correlation coefficient is also higher, being .89 ± .02 for potash, while it was .57 ± .05 for phosphoric acid. Comparisons made with total potash, acid-soluble potash (Table 2), water-soluble potash, and replaceable potash also bring out a close relation between the ability of the soil to supply potash as measured by these methods of chemical analysis and the results of the pot experiments. The estimation of active potash with 0.2N nitric acid is considered the most easy and the most reliable of the methods tested.

TABLE 2.—*Relation of the potash in the soil to the potash removed by two crops, corn and sorghum or kafir.*

Potash removed by two crops in p.p.m. of soil	Number of soils averaged	Potash in two crops in p.p.m. of soil	Average per crop in p.p.m. of soil	Active potash in soil in p.p.m.	Total potash in soil, %	Acid-soluble potash in soil, %
0–50	14	42	21	66	0.43	0.07
51–100	57	77	39	85	0.59	0.11
101–150	55	122	62	128	0.79	0.23
151–200	45	173	87	164	0.99	0.29
201–250	35	226	113	244	1.17	0.46
251–300	15	270	135	306	1.53	0.65
301–400	30	347	174	349	1.43	0.63
401–500	14	433	217	352	1.30	0.61
501–600	7	539	270	801	1.89	0.93
Over 600	—	665	333	628	1.79	1.14

A close relation between the loss of active potash from the soil due to cropping, and the potash removed by the crops from the soils (17) is shown in Table 3, and an even closer relation is shown for the replaceable potash.

TABLE 3.—*Relation of potash taken from the soil by crops to the active and the replaceable potash lost by the cropping, in p.p.m. in the soil.*

Group according to potash removed by crop	Number of soils	Average potash in crops	Active potash lost by cropping	Replaceable potash lost by cropping
0–50	11	42	16	20
51–100	20	79	24	30
101–200	31	145	42	61
201–300	1	238	35	54
401–500	1	460	68	277
501–600	3	527	309	311
601–700	4	639	171	221
701–800	1	735	140	391

It is evident that there is a close relation between the capacity of the soil to supply potash as measured by chemical analysis and the potash withdrawn by crops in the pot experiments. The effect of removing the potash from the soil by the crop is also reflected in the quantity of active potash left in the cropped soil. That the chemical analysis shows the effect of the potash removed by cropping is further evidence of the importance of the method for the analysis and investigation of soils.

The following is a summary of the correlation coefficients secured with different forms of potash in the soil (16):

Water-soluble potash and potash in two crops, $+ .70 \pm .02$
Water-soluble potash and active potash, $+ .79 \pm .02$
Potash soluble in 12% hydrochloric acid and potash in two crops, $+ .72 \pm .02$.
Replaceable potash and potash in two crops, $+ .91 \pm .01$
Replaceable potash and active potash, $+ .88 \pm .02$.
Active potash and potash in two crops, the same soils used for replaceable potash, $+ .89 \pm .02$.
Replaceable potash lost from the soil in cropping and potash in the crop grown, $+ .80 \pm .03$.
Active potash lost from the soil in cropping, the same soils used for replaceable potash, and potash in the crops grown, $+ .78 \pm .03$.

An attempt was made to separate the effect of the active, acid-soluble, and total potash upon the potash removed by crops. As calculated from the correlation coefficients (16), the relative results are as follows:

a (total potash)	= 0.189
b (acid-soluble potash)	= 0.013
c (active potash)	= 0.669
o (other factors)	= 0 520

These results are evidence that the effect of the active potash is much greater than that of the total potash or acid-soluble potash.

NITROGEN

While nitrogen is not an ash constituent, its importance justifies referring to the relations between chemical analysis and the nitrogen taken up by crops in pot experiments. The relation of the total nitrogen of the soil to the capacity of the soil (9, 13, 15) to supply nitrogen to crops in pot experiments (15) is shown in Table 4. It is seen that there is a close relation. The correlation coefficient for four crops is $.653 \pm .029$.

TABLE 4.—*Relation of nitrogen removed by four crops to the percentage of nitrogen in the soil.*

Grouping of soils in percentage of nitrogen	Number of soils	Average percentage nitrogen in soils	Nitrogen in crops in p.p.m. of soils
0–0.020	4	0.015	9.3
0.021–0.040	55	0.033	10.0
0.041–0.060	54	0.050	10.9
0.061–0.080	30	0.069	12.7
0.081–0.100	23	0.092	18.2
0.101–0.120	9	0.111	24.1
0.121–0.140	12	0.131	19.6
0.141–0.160	7	0.152	29.7
Over 0.160	8	0.194	39.5

The relation of the nitrate production in the soil to the capacity of the soil to supply nitrogen in pot experiments is shown (15) in Table 5. The correlation coefficient between the nitric nitrogen produced in experiments and the nitrogen taken up by the first crop in pot experiments is + .708 ± .025. Here also there is a close relation.

TABLE 5.—*Average relation of nitrogen taken up by a crop to the nitric nitrogen produced in the soil.*

Group based on nitrogen removed by first crop in p.p.m.	Average nitrogen in crop in p.p.m. of soil	Available nitric nitrogen in p.p.m. of soil	Percentage nitrogen in soil
0–8	20.91	43.4	0.058
8.1–16	17.83	23.2	0.044
16.1–24	25.47	33.3	0.052
24.1–32	35.47	44.6	0.073
32.1–40	49.67	49.9	0.087
40.1–48	54.80	69.9	0.107
48.1–64	66.80	57.2	0.062
Over 64	123.87	124.5	0.121

RELATIVE CAPACITY OF SOILS TO SUPPLY THE THREE KINDS OF PLANT FOOD

The comparison of the relations between the phosphoric acid, nitrogen, and potash which a particular soil can furnish as brought out by chemical analysis has been made at the Texas Experiment Station by means of the "corn possibility." By corn possibility is meant the number of bushels of corn that would be produced from the plant food considered from 2 million pounds of soil to the acre, if 0.625 pound of phosphoric acid, 1.5 pounds of nitrogen, or 1 pound of potash were required to produce 1 bushel of corn. The figures are based upon the plant food withdrawn by crops in the pot experiments for soils containing the various amounts of plant food. This

method is believed to bring out more clearly than a direct comparison of p. p. m. of plant food which one of the three plant foods is likely to be most deficient or less deficient, for the reason that there are considerable differences in the amounts of the three plant foods used by the same crop.

The corn possibility is used merely as a method of comparing the efficiency of the quantities of the different plant foods which the soil may furnish and is not intended to designate what the soil will produce in the field. Other factors enter into field production.

Tables 6 (12) and 7 (16) show the comparative corn possibility based upon pot experiments for the various amounts of plant food found in the analysis as used at the Texas Experiment Station.

TABLE 6.—*Corn possibility in bushels per acre based on pot experiments corresponding to active phosphoric acid or total nitrogen in the soil.*

Active phosphoric acid in p.p.m.	Corn possibility of phosphoric acid, bushels	Nitrogen in soil, %	Corn possibility of nitrogen, bushels
0–10	6	0–0.02	8
11–20	12	0.021–0.04	13
21–30	18	0.041–0.06	18
31–40	24	0.061–0.08	23
41–60	30	0.081–0.10	28
61–80	35	0.101–0.12	33
81–100	40	0.121–0.14	38
101–200	45	0.141–0.16	43
201–400	50	0.161–0.18	48
401–600	55	0.181–0.20	53
601–800	60	0.201–0.22	58
801–1000	65	0.221–0.24	63

RELATION OF CHEMICAL ANALYSIS TO CAPACITY OF THE SOIL TO FURNISH PLANT FOOD

Comparison of the chemical analyses with the capacity of the soil to furnish plant food in pot or field experiments have chiefly been for that part soluble in 1% citric acid in Europe and in 0.2N nitric acid in this country. The European comparisons chiefly show to what extent the conclusion that the soil was deficient or not deficient in the element studied by the method and standards used agreed with the results of pot or field experiments or of plant tests by the Neubauer method. Some of the workers found an agreement of 70% or more (7).

The American experiments compared the results of the chemical analyses with the amount of plant food withdrawn in pot experiments. It is obvious, from what has been said, that the relations are sufficiently close to justify the extensive use of the chemical analyses referred to in agricultural surveys and investigations.

TABLE 7.—*Corn possibility in bushels per acre, based upon pot experiments, corresponding to the active potash of the series.*

Active potash in p.p.m.	Possibility of corn, bushels
25-50	26
50.1-75	38
75.1-100	50
100.1-125	61
125.1-150	73
150.1-175	84
175.1-200	94
200.1-225	105
225.1-250	115
250.1-275	125
275.1-300	135
300.1-325	144
325.1-350	154
350.1-375	163
375.1-400	171
400.1-425	180
425.1-450	188
450.1-475	196
475.1-500	204
500.1-525	211
525.1-550	219
550.1-575	226
575.1-600	232
600.1-625	239
625.1-650	245
650.1-675	251
675.1-700	256
700.1-725	262
725.1-750	268
750.1-775	273
775.1-800	277
800.1-825	282
825.1-850	286
850.1-875	290
875.1-900	294
900.1-925	297
925.1-950	301
950.1-975	304
975.1-1000 up	306

RELATION OF CHEMICAL ANALYSIS TO DEFICIENCY AS SHOWN IN FIELD RESULTS

As already pointed out, the relations of the chemical analyses to soil fertility, as shown in field experiments, is more difficult to determine than are their relations to the capacity of the soil to furnish plant food, on account of the greater number of factors which influence the utilization of the plant food in the soil by the plants under field conditions. Comparisons between the chemical methods and the interpretation of the field tests have been made by a number of foreign workers. References to such work are given by Elleder (7), Lemmermann (20), and Koenig and Hasenbaumer (19). Results

for phosphoric acid with 1% citric acid have been said to be 80% accurate by Arrhenius (in Sweden and Java), 75% to 83% by Nemec, and 85% by Elleder.

No extensive comparisons of analyses with field results made in the United States have come to the attention of the writer. The wide range of soils, crops, and climate in this country involves a wide spread of variable field conditions. Extensive data are needed to apply the chemical analyses to varied conditions. The data available in the United States at the present time are relatively meager. Analyses showing the active plant food are usually not given in connection with field experiments and, even when made, they usually consist of estimations of total phosphoric acid, total potash, and other determinations not closely related to the capacity of the soil to furnish plant food. It is hoped that data for a scientific study of these relations will become increasingly abundant in the near future and will be published in full so as to give opportunity for study. Workers in foreign countries have supplied much more detailed comparisons.

Standards of interpretation have been proposed by various workers, but no single standard is applicable to all crops and all conditions. Proposed standards must be considered in connection with the soil, crop, climate, and possible yield. Lemmermann (20) believes that a soil is probably not deficient in phosphoric acid if more than 250 p. p. m. of phosphoric acid soluble in citric acid are present and if more than 25% of the total phosphoric acid is soluble. If less than 200 p. p. m. phosphoric acid soluble in 1% citric acid are present with less than 20% soluble, the soil will probably need phosphoric acid. Koenig and Hasenbaumer (19) set the limit at 250 p. p. m. for phosphoric acid, 160 p. p. m. for potash soluble in 1% citric acid, and 150 p. p. m. for nitrogen soluble in potassium sulfate. Dyer set the minimum limit at 100 p. p. m. for phosphoric acid or potash, and Stoddard at 150 p. p. m. for phosphoric acid.

Bray (3) has proposed a colorimetric method for field tests which, at the Texas Station, has been found to give variable results with different analysts or to the same analyst at different times. Table 8

TABLE 8.—*Number of soils as classed by the Bray method and by active phosphoric acid.*

Class by Bray method	Total	Active phosphoric acid in p.p.m.				
		5–10	10.1–20	20.1–30	30.1–50	Over 50
Low	23	10	12	1	0	0
Doubtful	14	5	7	2	0	0
Medium	33	5	13	11	4	–
High	47	0	6	8	22	12

shows the grouping of some soils by Bray's method and by active phosphoric acid. Soils containing over 30 p. p. m. of active phosphoric acid are generally classed high in phosphoric acid by the method.

Truog (2) has proposed a method involving the use of 0.002N sulfuric acid and uses 85 p. p. m. of phosphoric acid as the minimum for heavier Wisconsin soils and 57 p. p. m. for lighter soils, but presents no data which would enable one to judge of the adequacy of the method or of its relation to the older methods. He believes that 23 to 35 p. p. m. of phosphoric acid may be sufficient for corn in certain sections of the South.

There must necessarily be a variation in the limit of adequacy, depending on the climate, crops grown, and possible production of the soil when freely supplied with plant food.

TO WHAT EXTENT IS THE INTERPRETATION ACCURATE?

Some foreign investigators claim that the interpretation of the analysis for phosphoric acid or potash by means of 1% citric acid, so far as deficiency or non-deficiency exists, is correct to the extent of about 80% or more. That the method enjoys considerable prestige and is considered to be of practical value is shown by the fact that during the last three years in Germany about 55,000 samples of soil (21) have been tested for deficiency in phosphoric acid and potash for individual farmers by the citric acid method or by Neubauer's method. It is interesting to note that 69.4% of the samples were classed as deficient in phosphoric acid and 45.6% were deficient in potash.

Sufficient data are not available in the United States on which to base standards of interpretation suited to the different sections with their varying conditions of crops and climate. We are not in position, therefore, to judge of the accuracy of the interpretation so far as field results are concerned.

The chemical analysis is related to the capacity of the soil to supply plant food, but when application is made of the results to field work other important factors enter into play. The most important of these are perhaps (a) the kind of crop and its ability to assimilate plant food (18, 22), (b) the quantity of plant food required for optimum growth, (c) the depth of the soil and the extent to which it is occupied by roots, (d) the water provided by soil and season, (e) the temperature, and (f) the maximum size of the crop possible under the prevailing soil and climatic conditions. It is obvious that a plant having twice the capacity of another to assimilate phosphoric acid

will need only half the quantity in the soil; that a soil furnishing enough phosphoric acid for 30 bushels of corn may not contain enough for 50; that a soil which can be occupied to a depth of 6 inches furnishes only half the plant food provided by one that is occupied to a depth of 12 inches; and that a soil may contain enough plant food for 30 bushels of corn and not enough for a large crop of tomatoes.

Different standards of interpretation will be needed in different parts of the country, or for different crops in the same section, or for widely different soil types in the same section. It is obvious that a great amount of work yet remains to be done on tracing out the necessity relations.

CHARACTER OF INTERPRETATION

Chemical analysis cannot be used as an exact measure of the fertility of soil in some particular plant food, but can be used to divide the soils into groups within which other factors come into play that may have greater influence than the plant food studied. That is to say, with soils which differ to a decided extent in plant food, we would also expect corresponding differences in their reaction to the plant food studied, not exact but approximate. Soils of the same group as regards a particular plant food may also differ in their reaction to plant food on account of the play of other factors, but these differences within the groups should be smaller than without the group. The fact must be emphasized that the quantity of potash, phosphoric acid, or nitrogen in the soil is only one of the factors which influence the relation of the plant food to the crop, and while it is important as regards soil fertility, the fact that the chemical content is only one factor must not be forgotten.

The interpretation of the analysis had best be confined to a statement that the soil is low, doubtful, medium, or high in the plant food considered, as was done by Bray (3). The relations between chemical analysis and pot experiments can aid materially in deciding upon the limits to be set for the various sections, crops, and conditions. An accuracy of perhaps 80% in such a classification can be anticipated when sufficient experience has been secured regarding the climatic, crop, and other factors involved, so that they can be taken into consideration.

This degree of accuracy does not exist at the present time, and this field of work offers promising possibilities to the investigator.

SUMMARY

The capacity of a soil to supply plant food is only one of a group of factors which determines how much plant food can be taken up

by the crop, or what use can be made of it. The other factors include depth of the soil, its physical character, the kind of crop grown, climatic conditions, and others. There are close relations between the plant food removed in pot experiments and the chemical analysis of the soil for total nitrogen, and for phosphoric acid and potash soluble in 1% citric acid or 0.2N nitric acid, as well as for other weak solvents. The chemical analysis offers a fairly accurate method of comparing the potential fertility of various types of soils, or the relative abundance or deficiency of nitrogen, phosphoric acid, or potash in a particular soil. In applying the chemical analyses to field work, the analyses can be grouped according to the quantities of plant food present, and the interpretation made according to the kind of crop to be grown, the characteristics of the soil type, and climatic or other factors which may affect the power of the plant to use the plant food. Chemical analyses in connection with field experiments are needed in order to set up standards of interpretation applicable to different soils, crops, and climatic conditions in various parts of the United States.

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THE DIAGNOSTIC VALUE OF PLANT SYMPTOMS IN DETERMINING NUTRIENT DEFICIENCIES OF SOILS[1]

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Determining the nutrient deficiencies of soils is one of the most important of agronomic problems. The success of the farmer, the economical and intelligent use of fertilizers, and, in fact, a continued adequate food supply depend to a considerable extent upon how readily soil deficiencies can be recognized and how efficiently such information can be utilized. Numerous methods have been proposed for estimating the nutrient deficiencies of soils. There are the chemical methods, the micro-biological methods, the vegetation pots methods, and the field plat methods.

THE OBJECT OF DIAGNOSTIC METHODS

The object of all these diagnostic methods is to detect nutrient deficiencies, to distinguish which of the several nutrients is lacking, and to estimate the amounts needed to give the maximum yield and quality in crops. This at once centers them around the plant, or particular crop grown, and makes it necessary to judge their effectiveness by the precision with which they indicate just what the plant is lacking. The plant, if given careful study, can assist very much in this regard. By its unusual growth characteristics, by the variation in foliage colors, and in other ways, it is often possible to judge what is lacking and to determine the treatment necessary.

INVESTIGATIONAL WORK

In investigational work designed to study particular soil deficiencies, plant symptoms can be used to advantage. An excellent illustration of this is afforded by the study (3)[3] with magnesium made at the Massachusetts Agricultural Experiment Station. On one of the old experiment fields, a soil condition developed which caused a chlorosis on corn, manifesting itself chiefly by a striping of the leaves. The tissue between the veins turned yellow, and in the late stages brown, while that immediately surrounding the veins retained the normal green color. After considering a number of the

[1]Contribution from the Agricultural Department, The Koppers Research Corporation, Ligonier, Pa. Presented as part of the symposium on "Diagnosing Soil Deficiencies and Crop Needs" at the meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication December 8, 1930.

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[3]Reference by number is to "Literature Cited," p. 356.

factors involved, the hypothesis was advanced that the chlorosis was due to a lack of soil magnesium.

While it is true that the chemical, vegetative pot, and field plat methods all contributed to the solution, it was the consideration of plant symptoms which gave the greatest confidence in the final conclusion. Garner and his associates (1) had described the symptoms of magnesium hunger on tobacco. The writer, who happened to be doing the work, was familiar with the signs of a lack of soil magnesium as they appear on the tobacco plant. They are quite different from the chlorosis noted on the corn and it was impossible to draw any conclusion by comparing the symptoms on the two plants. But by planting two rows of tobacco through each corn plat, and treating one-half with magnesium sulfate and leaving the other half untreated, it was found that on the untreated areas a severe case of sand drown on the tobacco and chlorosis on the corn occurred. Where the magnesium sulfate was used these chlorotic effects were absent.

The question naturally arising from such results was whether the effective element in the treatment was magnesium or sulfur. By reference to the tobacco, it was quite evident that magnesium was lacking in the soil. This conclusion was justified by the fact that the chlorosis on the tobacco of the untreated plats was the typical sand drown, a malnutritional trouble known to be due to a lack of magnesium. These observations were confirmed by other tests.

As a result of this work, it was recommended to the farmers of Massachusetts (4) that they test their soil for magnesium. The test consisted in observing the foliage characteristics of tobacco and corn during July and August. About this time of the growing season, if the soil is lacking magnesium, the striped effect on corn and the mottled effect on tobacco appear. Many farmers learned by this procedure the explanation of a phenomenon they had been observing for sometime. Especially were the tobacco growers keen to take the suggestion because the lack of magnesium impaired the quality as well as the yield of their product.

FIELD WORK

The significance of plant symptoms means more to the man in the field and to the farmer than to anyone else. Neither of these men have time to resort to elaborate tests. What they desire is to be able to interpret the meaning of the various types of plant responses as they appear on different fields and farms. This can be done to a limited extent, and because of information available, with some plants more than with others.

The tobacco plant has received considerable attention as an indicator of soil deficiencies, and perhaps with tobacco, more than with most crop plants, the experienced field man can judge the soil merely by inspection of the growth characteristics. Very precise descriptions of the manner in which deficiency in potash, magnesium, calcium (5), phosphorus, and nitrogen (6) affect growth have been recorded. Acquaintance with these records makes it possible to determine almost at a glance what is lacking in the fertilization of a given field of tobacco.

LIMITATIONS IN USE OF PLANT SYMPTOMS

Plant symptoms as indicators of soil fertility also have their limitations. Unlike tobacco, many crops do not show such striking symptoms of soil deficiencies that they can be regarded as entirely reliable. Morgan (2), in studying fertilizer requirements of several important soil types in Connecticut, employed a number of crops in pot cultures. Of those used, *viz.*, alfalfa, corn, lettuce, carrots, beets, onions, buckwheat, barley, and tobacco, tobacco was the most satisfactory. This work not only suggests a variation among plants as regards the value of their deficiency symptoms in indicating soil fertility, but also explains why the fertility of a tobacco field can be so effectively judged by the appearance of the crop.

While, in some cases, it is possible to judge a deficiency symptom on a particular crop by comparison with the way in which it affects other crops, such a procedure can be misleading. A lack of nitrogen with a number of crops generally causes the foliage to take on a light yellow color. If this be true, it would seem reasonable in case the observer is not acquainted with the symptoms of nitrogen deficiency on a particular crop to draw upon his experience with other crops and conclude nitrogen is lacking in the soil simply because of the characteristic yellow appearance of the foliage. Yellow foliage can be caused by other means than a lack of soil nitrogen. Tobacco infected with black root-rot (2) frequently shows nitrogen starvation symptoms even with abundant nitrogen in the soil. The root-rot is the primary cause of the trouble and to conclude that the soil needs more nitrogen to remedy the situation would be an absolute mistake.

The appearance of a particular deficiency on one plant may be entirely different from that on another. A striking illustration is the appearance of magnesium hunger on corn and tobacco, described above. On careful examination, however, tobacco and corn are not so different in their response to deficient magnesium. The important difference is between the plants themselves, one being a monocotyledon with parallel veins and the other a dicotyledon with irregularly

branching veins. The yellowing and dying of the tissue between the veins would naturally give a striped effect on the corn and a mottled effect on the tobacco. But without such understanding of the situation it would be very misleading to attempt to diagnose magnesia hunger on one of these plants merely from an acquaintance with the symptoms on the other.

In the fractional application of fertilizers, the signs of a shortage in plant food, as indicated by plant response, are often used as a guide to determine what and how much treatment should be given. Such a procedure is more effective with some crops than with others, but if followed systematically it is doubtful if in any case the maximum return can be secured. To furnish a continuous supply of nitrogen for tobacco through the growing season it is the practice, especially in the Connecticut Valley, to apply very little of the nitrogen in the readily available forms, but to supply most of it in the slowly available and more expensive forms. If the growers were wise enough, they might take advantage of the fractional application principle and grow the same high quality of tobacco with the cheaper forms of nitrogen. One reason why they are unable to do this is their inability to judge just when the different applications should be made. Their only guide is the appearance of the crop, and if they wait until the typical symptoms of nitrogen starvation appear, it is too late, because the damage has already been done. There is usually a lag of two weeks or more, depending on the season, between the time when a shortage of nitrogen begins to affect the crop and the appearance of typical starvation symptoms. Where quality is of such great importance, retardation of growth, even for a few days, is of serious consequence. Thus, it is evident that plant symptoms are not entirely dependable as indices of the proper time to make fractional applications of fertilizers.

NEED FOR MORE INFORMATION

For plant symptoms to be of greatest use, much more information is needed regarding their meaning. In the last edition of his book, Sir John Russell (7) presents a table entitled, "Plant Appearances as Diagnostic of External Conditions." Very few writers on soil fertility have attempted such a thing, and when one considers the inadequacy of this table, not only is the reason evident but the lack of available information indicated is striking. If such a table as presented by Sir John Russell could be made more complete with accompanying illustrations it would prove of great value. What is needed is a complete description for all crop plants of the appearance

induced by deficiency in the various nutrients under field conditions. There is considerable information scattered through the literature bearing on this point, but the writer believes there is even more in the files of agronomists who have given this subject special study. To be sure, deficiency of some of the recognized essential nutrients has not been noted in the field, and in such cases, the descriptions could be given for the conditions under which observed. It would also be of interest to know how closely the deficiency symptoms in greenhouse cultures of different sorts correspond with those found in the field.

GREATEST VALUE OF PLANT SYMPTOMS

In the present stage of development perhaps the greatest value of plant symptoms in determining nutrient deficiencies is their relation to other methods. Like all methods the indications of plant symptoms frequently need supporting evidence to justify a conclusion. When other methods are applied with a result that corresponds with the indications given by the plant, the investigator usually has confidence that he is approaching the solution of his problem. On the other hand, he is not satisfied, even in the face of strong evidence from various tests, if they are contrary to what the plant itself shows. This should be regarded as a desirable situation lest agronomists be misled by neglect of the plant and too great emphasis on laboratory tests.

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THE NATIONAL PROGRAM OF SOIL AND WATER CONSERVATION[1]

H. H. BENNETT[2]

THE PROBLEM

Erosional wastage of soil and excessive loss of rainwater from unprotected cultivated slopes and from overgrazed ranges and pastures have come to be recognized as American economic problems of grave national importance. The two processes of wastage go hand in hand, and the resulting evils are manifold. Not only is the productive topsoil being made thin by the unceasing attack of runoff water, but it is being swept away completely from countless slopes, leaving behind subsoil, which invariably is less productive and usually is more difficult and costly to till. In many instances, following the washing off of this vitally important humus layer and then of the layers beneath, the exposed material in numerous parts of the country erodes faster than the upper soil layers. Also, the exposed subsoil of many types of land is less absorptive of rainwater than was the soil removed by washing, and is less retentive of the water which is absorbed, the clayey material so often exposed being more impervious when wet and more susceptible to hardening, cracking, and loss of moisture on drying.

In many localities, as the result of prolonged erosion, increased amounts of solid soil matter, dissolved constituents, suspended colloids, and water are being swept into the valleys and into stream channels, drainage and irrigation canals and ditches, reservoirs, lakes, and harbors. Lower slopes and alluvial plains are being covered on a large scale by soil started toward the sea, but stranded somewhere en route to that final destination. These sediments are injuring fields, meadows, woodlands, and protective brush and grass-covered areas. Frequently, they consist of sand and gravel having either no crop value or a tremendously reduced crop value as compared with the soil buried by them. With the clogging of stream channels, possibilities of navigation are reduced or destroyed and former cultivable fields are made uncultivable or useless by reason of the increased frequency and duration of overflows. Indeed, some millions of acres of formerly tilled land have thus been converted into

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Presented as part of the symposium on "An Extension Program for the Control of Soil Erosion" at the meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication December 8, 1930.

[2]In Charge, Soil Erosion and Moisture Conservation Investigations.

marshland and near marshland without crop value, as witnessed in the numerous areas of recently formed "meadow," a semi-swamp type of land mapped in hundreds of stream bottoms throughout the Piedmont region.

In its effects upon agricultural and pastoral lands, the maleficence of erosion over many millions of acres does not stop merely with the planing off of the upper soil layers, changing vast areas from productive mellow loams, silt loams, and sandy loams to relatively unproductive, intractable clays and clay loams; but goes on to the point of destroying, insofar as cultivation is concerned, both uplands and stream bottoms, as in the instance of channel erosion in the valley lands of the dry West and Southwest, by gulleying. This insidious dissection proceeds with such rapidity in some of the more vulnerable regions that control measures scarcely come within the scope of practical farm operations, especially where procrastination has permitted the gulleys to dig deeply into the less stable substrata characterizing many types of soil. On some steeply sloping lands, gulleys cut down to bedrock within four or five years following the removal of the virgin cover of timber, grass, or chaparral. Observation and surveys indicate that erosion, accelerated by the intervention of man's agricultural and livestock operations, is affecting not less than 75% of all the land in cultivation in the United States; and that impoverishing washing, with its attending diminution of the growth of nutritious grazing plants, resulting from overgrazing, is affecting between 75 and 90% of the western ranges and a considerable part of the pastures and ranges of the more humid regions.

The damage of erosion varies greatly, as a matter of course, due to differences in soil, slope, character and amount of rainfall, vegetative cover, and past and present usage. Soils high in content of silt, sandy loams, and loams overlying less absorptive clay layers, clays that undergo marked granulation and fragmentation on drying, and practically all soils of low organic-matter content are the more susceptible to rapid wastage by sheet erosion. Soils with substrata of a less stable character than the overlying layers, such as those having loose, sandy, and gravelly beds and soft, silty layers, and decomposed ("rotten") rock in their lower depths, suffer more disastrously from deep-going and rapidly extending gulleys than those types having clay and silty layers of good permeability beneath their upper layers. Soils with impervious sub-layers are far more erosive than those with permeable substrata, that is, where the lower beds do not consist of excessively fragile material, such as melt away in contact with flowing water after the manner of sugar. The steeper

areas are usually more erosive, where the soil and soil treatment are comparable, as are, also, the less densely vegetated areas and areas kept loose at the surface by shallow cultivation and excessive trampling of stock. There are exceptions to these general characterizations, but they are not nearly so important in areal representation.

The wide differences in susceptibility to destructive washing due to such variables as those referred to and, in some instances, to the manner in which erosion proceeds (erosion types), necessitate the use of varying control measures in attempts at slowing down or controlling the washing. Regions of heavy rainfall characterized by hard showers are likely to call for measures which may not prove practicable when applied to other regions where the total precipitation is lighter and the rains fall more gently. Erosion by melting snow may not necessarily be controlled in precisely the same manner as that caused by rainfall.

Where the effect is primarily to conserve water, again different methods of procedure may be required. Where wind is the chief factor or a markedly important factor in connection with soil removal, still other methods must be brought into use. The effects of gravitational creep, sliding, and soil fragmentation may also call for special control measures. Widely trenching gulleys with caving walls, such as characterized soils having loose or soft substrata, require different types of control dams than the V-shaped gulleys which characteristically form in stiff, impermeable clays. Areas subject to rill washing, as distinguished from the plantation effects of sheet erosion, seemingly can not be controlled by precisely the same methods as employed in handling the latter type of washing.

Accordingly, the problem of erosion control and water conservation is not one where a few simple methods of attack are likely to give widespread results of a satisfactory nature. Indeed, the process is so varied from place to place, due to natural and induced variables, that any effective control obviously will require the use of many different measures. So little attention has been devoted to the problem of land impairment by excessive washing, even though it doubtless exceeds the impairment caused by all the other agencies (of human intervention) affecting soil productivity, that we stand today essentially at the threshold of endeavor, insofar as relating to a clear understanding of erosional processes and the development of practical methods of erosion control or diminishment. Until recently, quantitative data dealing with erosion were almost completely lacking. Even now, little is known either as to the rate or type of erosion for most soils, particularly as they occur on varying

slopes, under varying cropping systems. These fundamental data are vitally essential in connection with any sound understanding of the processes involved and with any certainty of procedure in the matter of control measures, as is true of other problems relating to soil depreciation.

It was not until recently that unnatural or abnormal erosion, as distinguished from the much slower and less vicious kind of erosion which goes on under natural or normal conditions of ground cover and soil structure, was clearly defined. Broadly speaking, the former type of washing, that is, man-induced or man-accentuated erosion, was looked upon, until lately, as belonging to the natural order of erosional activities. As a matter of emphasis, it may not, perhaps, be amiss to repeat what has already been inferred, namely, that the national program of soil and water conservation, with which this paper is concerned, relates primarily to the abnormal phase of soil erosion—that which results from the activities of man and his domestic animals in breaking down natural soil conditions and stabilizers through the complete or excessive removal of vegetation and the disruption or destruction of the normal or natural soil structure by cultivation, trampling, and other means. And, too, it may be well to emphasize the point that this national program is concerned chiefly with soil and water conservation, rather than with reclamation of areas already despoiled; although, of course, efforts will be made to determine the cost and feasibility of reclaiming such devastated lands.

METHODS OF CONTROL

Fortunately, experiments aimed at the determination of the principles underlying soil erosion processes will, in a considerable degree, reveal, concomitantly, methods of land use which are likely to prove most effective in slowing down excessive soil losses by washing. In other words, the methods of research employed are likely to be, necessarily, at least in a considerable number of instances, demonstrational as well as investigational in character.

From what has been said in regard to the variables of erosion, manifestly, the investigations must be carried out on a regional basis, that is to say, on the basis of the major agricultural soils or soil groups of the country and the major climatic zones. The subordinate variables, such as slope and condition of the soil as affected by different methods of use, must, of course, be given due consideration. The latter, though varying widely within narrow limits, may be classed as local variables, rather than regional, since they may affect most of the regions in more or less the same manner, though not necessarily in the same degree.

The major problems as affected by these variables will be attacked first, according to the program as at present outlined; and these under as nearly average or representative conditions for the more important regions as may be scientifically practicable. Naturally, the saving of soil will be emphasized in those more humid regions, where soil losses are of more importance to the users of land than are water losses. Conversely, the saving of water will be given most consideration in those dry regions where the amount of rainfall loss by runoff frequently determines the failure or success of an agricultural enterprise. Some modifications of this general plan of attack will necessarily be made in those relatively dry regions where soil shifting by wind is of greater concern to the farmer than are losses of water and soil in the runoff.

OUTLINE OF THE PROGRAM

The program of investigations, as outlined by those who have critically studied the numerous variables and objectives involved, splits along six major lines, as follows: (1) *Soil* and *soil-agronomic* investigations, (2) *collateral soil* and *soil-agronomic* investigations, (3) *soil-engineering* and *soil-engineering-agronomic* investigations, (4) *soil-vegetative* investigations, (5) surveys, and (6) educational and extension activities.

In reality, it will be impractical, even impossible, to draw sharp lines of separation between the numerous problems to be investigated under these major groupings; indeed, no such demarkation appears to be particularly necessary, since each of the variables or problems will be individually investigated at some point in the program, from as many angles of attack as may be necessary for a clear understanding of the processes involved and of the relation of these processes, and their attendant problems, to one another, as well as for the determination of practical means of control or prevention.

Owing to the limitations of this paper, it will be impossible to enumerate more than briefly the principal lines of work to be taken up. Additional problems undoubtedly will come up from time to time as the work proceeds. Indeed, such has been the case since the inception of the program two years ago.

A—SOIL AND SOIL-AGRONOMIC INVESTIGATIONS

1. Measurement of the rate of erosion for the major regional soil types as affected by:
   a —degree of slope
   b —length of slope

c —soil condition due to past treatment
d —amount and character of rainfall
e —seasonal condition (chiefly as relating to the effects of drought, long periods of saturated ground, freezing, and thawing)
f —continuous use for single crops
g —cropping schemes, such as crop rotations
h —fallowing alternating with cropping
i —strip cropping
j —tillage methods
k —additions of artificial fertilizers and soil amendments, crop residues, and green-manuring materials
l —erosion pavement conditions
m—no treatment (check plats of bare ground)
n —no treatment (grass plats or plats of other native vegetation)

2. Measurements of water losses from varying slopes as affected by the natural and induced variables enumerated under A-1.

3. Measurements of soil losses from various slopes in the solid, colloidal, and liquid state, as affected by the natural and induced variables enumerated under A-1 (to be determined by weight or volume measurements and by physical and chemical analyses of the runoff and washoff).

4. Measurement of changes in the soil under the natural and artificial conditions enumerated under A-1 (to be determined by continuing chemical and physical analyses of the soil under control and by depth changes in this soil as computed from pre-established bench-marks).

5. Measurement of rate and depth of water penetration, rate of percolation, and of the amount retained in the soil, as affected by erosion and runoff, under the several natural and artificial conditions enumerated under A-1 (to be accomplished by moisture determinations and percolation and runoff measurements on small plats and large plats duplicating, as nearly as possible, the conditions itemized under A-1).

6. Measurement of water losses by evaporation under the natural and artificial conditions enumerated under A-1 (if satisfactory means for such determinations can be worked out).

7. Determinations of the effect of erosion and excessive water losses on the yield and quality of crops.

With the plat-tank installations employed in connection with these experiments and quantitative measurements, operated under such control as to catch all the runoff and washoff, keeping each plat separated from the others by deep, waterproof dividers (accretions of

solid and dissolved matter in dust and rainwater being determined by means of special collectors placed about the plats), it is expected that the answer to the question of soil and water losses and accompanying chemical and physical changes in the soil will be fully determined. Biologic changes may not be so easily determined, although it is hoped that it may be possible to attack, effectively, this phase of the problem, also. If this can be done, then we shall have not only full quantitative expression of the underlying principles relating to erosion and water losses, as well as to the specific effects of erosion on definite soils, occupying definite slopes, subjected to varying climatic conditions and undergoing different cropping and tillage treatments; but, also, a full measure of the effects of such things as a crop rotation on a specific soil. With this information, we shall be better able to plan and devise methods for control and prevention of erosion and excessive water losses, as well as to advise farmers operating under these specific conditions not only as to what is going on in their fields, but as to what must be done in order to slow down or prevent the wastage of soil and water.

B—COLLATERAL SOIL AND SOIL-AGRONOMIC INVESTIGATIONS

1. Making use of both small and large plats, the effects of cropping schemes, tillage treatments, fertilization and green manuring, strip cropping, strip subsoiling, etc., in relation to restoral of soil conditions favoring resistance to erosion, are to be determined on uneroded and eroded soil (or soil desurfaced to simulate an eroded condition), occupying different slopes (the measurements to be made by observation, yield, runoff, and washoff).

2. Soil renewal experiments are to be carried on under the various treatments enumerated under A-1, in order to determine the precise effect of these treatments, under various conditions, in connection with the restoral of productivity of severely eroded land (the effectiveness of the treatments under these various conditions to be determined by observation, yield, and quality of the crops, and by the runoff and washoff).

3. Experiments with various grasses, shrubs, vines, trees, and soil-holding plants, such as sweet clover and lespedeza, are to be made in order to determine the most efficient and practical methods for controlling gulleys of the various types (as those of the branching V-shaped and caving types, lateral-extension type and head-on extension and eroding-bank types). Also, small living dams of grass, vines, and shrubs are to be tried in connection with the control of lesser gulleys.

4. Experiments with various plants, as those referred to under B-3, are to be made to determine the most efficient and practical methods for controlling erosion under such conditions as the eroding slopes of road cuts and embankments, earthen dams, and canal and ditch banks.

5. Experiments to determine the practical and economic limitations in the use of agronomic and soil-manipulation methods with respect to steepness of slope are to be carried out. Such investigations are expected to show at what degree of slope the use of the land for crops should give way to its use for permanent grass and forestry.

6. Investigations are to be made to determine the principles underlying the temporary and ultimate disposal of erosional débris and the effect of deposition of such material on agricultural lands, as influenced by soil, climate, vegetation, crops, and other factors relating to the eroding watersheds, on the one hand, and to the areas affected by over-wash, on the other hand. Such studies would include not only the effect of natural stands of vegetation on both the eroding watersheds and the areas receiving deposits, but also the effect of artificially established stands of vegetation.

7. Study of the effect of soil and subsoil materials and mixtures of these on the stability of such engineering structures as terraces and earthen dams is to be made (measurements of the relative efficiency of the materials to be made by observation of the holding capacity of such structures, aided by careful records of the mechanical composition of the soil in the structures at points of weakness and stability).

8. Experiments are to be carried on to determine the practical value of ordinary farm methods (regional) in comparison with (1) good farm methods and (2) with ordinary farm methods supplemented by terraces.

C—SOIL-ENGINEERING AND SOIL-ENGINEERING-AGRONOMIC INVESTIGATIONS[3]

1. Under this group of studies experiments and determinations are to be carried out for the purpose of ascertaining the most efficient means for controlling erosion and runoff, or for reducing the effects of erosion, by the use of such structures as field terraces of various grades, widths, heights, lengths, shape, and vertical intervals, for various soils, slopes, and climatic conditions; and, also, with artificial structures employed in connection with the control of wind erosion, gravitational creep, and slides. These experiments are to answer the

[3]See the first report of the Inter-Bureau Committee on Soil Erosion.

question, also, as to the effectiveness of such structures when used in conjunction with soil- and water-saving cropping schemes and tillage methods. Some of the principal initial lines of experimentation under the heading of control measures are as follows:

a —to determine for terraces of uniform grade the proper gradient, vertical interval, and cross-section

b —to determine for terraces of variable grade the proper gradient, vertical interval, and cross-section

c —to determine the maximum permissible length to which the above types of terraces can be safely constructed

d —to determine the types of soil and the maximum slopes upon which level terraces can be safely employed

e —to determine the maximum permissible length to which level terraces can be safely used

f —to determine the proper cross-section of level terraces for various vertical intervals

g —to determine the best methods and the cost of constructing terraces of various types

h —to determine the cost of and best methods for the maintenance of different types of terraces

i —to experiment with various types of terrace-building machinery, with the view of improving existing machinery and for developing new and more efficient machinery

j —study of the operation of farm machinery over terraced land, with the view of adapting the cross section of the terrace to the requirements of existing machinery and for indicating needed changes in present types of machinery, so as to permit its use over terraces as now constructed

k —to determine the most effective and practical means for preventing erosion at the ends of terraces

l —to determine the most efficient and practical methods of water disposal from terraced outlets

m—to determine the effect of terraces on farm operations

n —to determine the effect of cultural operations on erosion and runoff, with a view of aiding in the prevention and reduction of erosion by improved machinery

o —to determine the effect of various cropping schemes, used in conjunction with terraces and other structures, in reducing and preventing erosion and runoff

p —to determine the relation of intensity and time of rainfall to runoff and erosion and to the efficiency of terraces and other erosion-control structures

2. Measurement of the rates of runoff and erosion from terraced and unterraced areas to determine the effectiveness of the terraces in controlling erosion and runoff, and to obtain data upon which to base terrace design.

3. Measurement of changes in the soil as affected by terraces of various design, grade, and vertical interval, as outlined under C-1

(to be determined by crop yields and by physical and chemical analyses of the soil under observation, and by changes in soil depth, as ascertained by comparison with pre-established bench-marks).

4. Measurement of the rates of runoff from watersheds and drainage basins of various slopes and sizes, covered with various types of vegetation or partly covered with vegetation and partly cultivated, to determine the amount of water that must be taken care of in designing drainage and flood-control improvements; and to determine the effect of runoff and erosion, from such areas, on flood peaks and flood duration and on the volume of water passing down small streams.

5. Study of moisture absorption, percolation, and retention, as affected by the structures enumerated under C-1.

6. Experiments to determine the economic limitations in the use of terraces and other structures, with respect to steepness of slope.

7. Experiments to determine the most efficient and practical methods for controlling gulleys of various types by the use of dams of different composition and construction, employed alone and supplemented by such stabilizers as trees, shrubs, and grasses.

8. Experiments to determine the most effective methods for controlling small gulleys and for reclaiming land affected by such gulleys.

9. Experiments to determine the most efficient and economical materials to be used in gulley-control dams, as well as the most efficient types of equipment to be employed in building such structures.

10. To determine the maximum proportion of land which can be devoted to the major regional crops by the aid of terracing and other soil- and water-saving structures, without putting too much strain upon the efficiency of cropping schemes as at present practiced on unterraced land.

11. Experiments to determine the comparative value of ordinary farm practice (regional) and the same type of farming supplemented by terraces.

D—SOIL-VEGETATIVE INVESTIGATIONS[4]

Under this heading, studies and experiments are to be made to ascertain (1) the principles underlying erosion and runoff from areas of various soil, slope, and climatic environment, occupied by various natural and artificial stands of vegetation, undergoing different treatments; and (2) to determine the most efficient and practical

[4]See the first report of the Inter-Bureau Committee on Soil Erosion.

methods of erosion and runoff control. The principal initial lines of investigation will be carried out according to the following general plan:

1. Determinations to ascertain the rate of erosion and runoff for the major regional soil and vegetation types as affected by:

- a —degree of slope
- b —length of slope
- c —soil condition, due to past treatment (such as moderate grazing, overgrazing, frequent burning, and occasional burning)
- d —character and condition of natural vegetation
- e —character and condition of planted grasses, trees, and shrubs, and of such growths as may be influenced by regulation of grazing and by practice of good forestry methods

2. Measurement of water losses, quantitatively, from varying slopes, as affected by the natural and induced conditions enumerated under D-1.

3. Measurements of changes in the soil as affected by the artificial and induced conditions enumerated under D-1 (to be determined by physical and chemical analyses and by depth measurements of the soil under experimentation through comparison with pre-established bench-marks).

4. Experiments to determine the practical limitations in the employment of grazing-regulation methods, plantings, and, possibly, engineering structures, with respect to steepness of slope and other pertinent factors.

5. Measurements to determine the amount and rate of runoff and washoff from individual watersheds or groups of watersheds under various known conditions of soil, vegetation, topography and rainfall, and agricultural, pastoral, and forestal utilization.

6. To determine, by means of test plats under controlled conditions, the relation of intensity and time of rains falling on different degrees and character of vegetation to the character, amount, and rapidity of surface and sub-surface runoff and to erosion.

7. To determine by practical tests on experimental areas of sufficiently large size the influence of the vegetative cover (timber, brush, or herbaceous growths), and its depletion or entire removal by fire or otherwise, upon the character and amount of runoff and erosion, floods, usable water supply, etc., under different rainfall conditions and for different forest types.

8. To determine the economic loss from decreased runoff, increased erosion, flood danger, etc., caused by forest or range devastation.

9. To determine ways and means for preventing further erosion by re-establishing depleted timber, herbaceous, or shrubby vegetation, and by replacing present vegetation with species that are of more value for watershed protection because of fire resistance, more binding root systems, smaller water needs, etc. With this, there should be tried, perhaps, certain engineering works, such as check and wing-dams, terraces, and logging improvements to clear and maintain channels.

E—SURVEYS

Detailed and reconnaissance surveys are to be made of small plats, large fields, farms, drainage basins, and valley areas receiving deposits of erosional débris from crop lands, grazing and timber lands, and protection areas, i. e., areas under protection for the purpose of regulating stream flow, prevention of overwash upon slope and valley lands, and prevention of excessive silting of reservoirs, lakes, and harbors. These surveys will be of the following types, the intensity of detail depending on the purpose of the particular survey:

1. Detailed surveys.
   - a —detailed soil and soil-erosion surveys to show the area and distribution of the various soils and the depth to which erosion has proceeded on these soils, the soils to be classified and mapped according to the standard methods of the Bureau of Chemistry and Soils, and the degree of erosion to be determined by comparison with uneroded areas of the same soil occupying the same slope (making use of areas having the original type of vegetation, wherever available). The mapping will be carried out in accordance with methods employed in soil survey work.
   - b —surveys to be made as under E-1a, to show in addition to the condition and geographic distribution of erosion (1) the topographic features, (2) vegetative features, and (3) land utilization practices.

2. Reconnaissance erosion surveys of several different kinds to be made, according to needs, as follows:
   - a —to show the degree and distribution of erosion according to soil type
   - b —to show the degree and distribution of erosion without reference to soils
   - c —to show the degree of erosion without reference to its distribution
   - d —to show the degree and distribution of erosion according to major classifications of land usage
   - e —to show the degree and distribution of erosion according to major topographic features
   - f —to show the degree and distribution of erosion according to soil, topography, cultivation, and vegetation

3. In order to show all the features enumerated under E-1 and E-2, it will be necessary, first, to make detail or general topographic and vegetative surveys of the areas to be covered.

F—EDUCATION AND EXTENSION ACTIVITIES

1. Under these activities, it is proposed to carry on programs of education and extension work in order to (1) arouse land users, the nation, states, counties, and business men to the seriousness of the problem of erosion, its meaning and cost; (2) to point out the necessity for employing practical methods of control, emphasizing the fact that erosion is a business problem which must be solved now, and not one that can be put off for future generations to take care of; and (3) to carry direct to the farmers those practical results worked out at the regional soil erosion and moisture conservation experiment stations, which have been proved to be applicable to the local conditions. The problem of conserving more of the rainfall by causing more of it to sink into the ground where it falls and by diverting and spreading the runoff so as to be applied economically to lower lying areas, according to the water needs of such areas, should be emphasized, and any experimental results of proved practical value in this connection should be carried to the regional users of the lands, as suggested above in connection with erosion. This matter of saving more of the rainfall will, of course, apply chiefly to areas characterized by low precipitation, particularly to farms and ranges within and to the west of the Great Plains.

2. Educational dissemination of the facts relating to the causal and identifiable aspects of erosion, as well as to the cost of erosion in general and specific terms of land impoverished or destroyed; and the carrying of experimental results pertaining to practical methods of control and prevention directly to the land uses concerned can probably best be accomplished through the medium of the federal and state extension and information services, the state colleges of agriculture, and experiment stations; by the encouragement of visits to the erosion and moisture conservation experiment stations on the part of farmers, business men, teachers, and students; by publication and wide distribution of departmental and state bulletins, circulars, and progress reports; by newspaper, magazine, and farm-journal articles; and by illustrated lectures.

CONCLUSION

It is proposed under the national program of soil and water conservation to determine the efficacy, practicability, and cost of all

promising means relating to the prevention, control, and reduction of erosion and excessive runoff of rainwater, and to carry the results to those users of the land according to the specific needs and adaptabilities of their soils. Obviously, it is not going to be possible to work out all the details of such a comprehensive program at once. The various research projects and required experimental installations will be taken up in an orderly manner, in accordance with their apparent importance, when and so far as funds permit. Work on some phases of the problems will necessarily be delayed until certain preliminary pertinent facts are ascertained in connection with related problems. This is a new field of research; and in order to carry

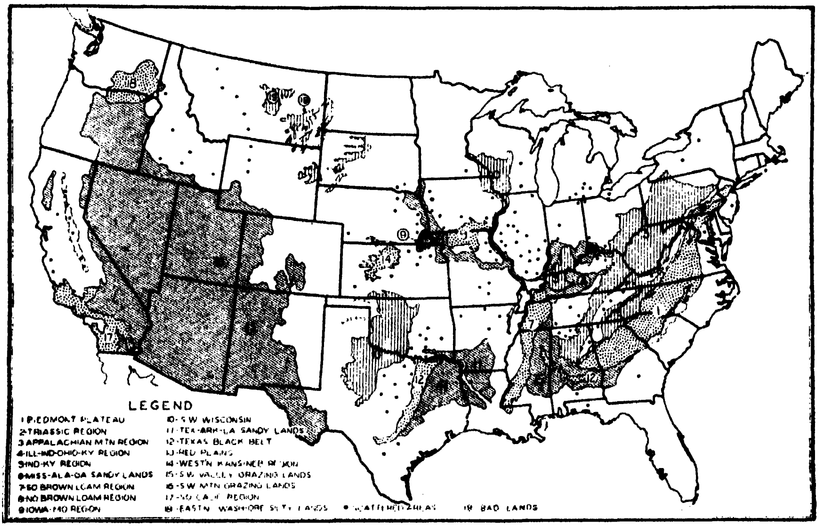

FIG 1.—Reconnoissance map of regional soil erosion areas.

it ahead in the most efficient manner, new methods of procedure must be worked out. Doubtless, some of the experiments outlined in this paper may have to be revised, and others added. It will not be in the least surprising if some lead to negative results.

It will be readily recognized by all of those who look searchingly into the problem of erosion that it embraces so many variables, so intricately inter-dependent, that time, patience, and a high degree of technical efficiency are going to be required to solve the problem in all of its varied ramifications. That this will be accomplished wholly or in a large degree is indicated by the good progress already made at the seven established stations.

In the preliminary plans for the establishment of the soil erosion and water conservation experiment stations, 19 major regions were roughly defined and outlined on a generalized map. These regions, as

designated, are shown in Table 1, which also includes the approximate areas of each. (See also Fig. 1.) It should be recognized that these regions represent nothing more than very general approximations of the location and extent of large sections of country in which it is known that erosion is actively damaging a number of more or less related soils of extensive occurrence, and that the processes of wastage are proceeding with certain characterizing similarities in each of the regions, due to similar soil, vegetative, climatic, and topographic features. Some of the larger regions are broadly inclusive with respect to these conditions.

TABLE 1.—*Areas of the major erosion regions.*

Designation	Approximate area, acres
Piedmont region	46,000,000
Appalachian region	78,000,000
Triassic region (sandstone and shale Piedmont country)	5,000,000
Illinois-Indiana-Ohio-Kentucky region	18,000,000
Indiana-Kentucky region	7,000,000
Mississippi-Alabama-Georgia Sandy Lands (coastal plain)	27,000,000
Southern Brown Loam region	17,000,000
Northern Brown Loam region (mainly loessial soils)	18,000,000
Iowa-Missouri-Nebraska-Kansas region (mainly Shelby soil erosion)	11,000,000
Southwestern Wisconsin region (with adjacent areas in Minnesota and Illinois)	12,000,000
Texas-Arkansas-Louisiana Sandy Lands (with small adjacent area in Oklahoma)	33,000,000
Texas-Alabama-Mississippi Black Belts	12,000,000
Texas-Oklahoma-Kansas Red Plains	36,000,000
Western Kansas-Nebraska region	36,000,000
Southwestern Valley Grazing Lands and Mountain Grazing Lands (collectively)	379,000,000
Southern California region	15,000,000
Washington-Oregon-Idaho Silty Lands	13,000,000
Bad Lands of the Dakotas, Montana, Wyoming and Nebraska	———

The fact should not be overlooked that erosional damage is not restricted to these regions, as now defined. Numerous lesser areas, embracing highly erosive crop and grazing lands, are scattered throughout the unclassified areas. In other words, the major erosion areas, as now outlined, constitute simply a preliminary working plan—a guide to be used in getting started a new program of research. With the aid of additional reconnaissance and detailed erosion surveys, it is planned to prepare a much more accurate statement with respect to the geographic aspects of erosion.

MODIFICATION OF SOIL NITROGEN AND ORGANIC MATTER BY AUSTRIAN WINTER PEAS[1]

MERRILL M. OVESON AND WILBUR L. POWERS[2]

Field peas have been the most promising of legumes for maintaining soil nitrogen and organic matter at the branch experiment stations at Moro and Burns, Oregon (17).[3] On the dry land experiment farm at Moro it has been found practical to grow peas annually. Peas have a short season of growth, their residues decay readily, and they do not so thoroughly exhaust the soil moisture that succeeding crops "burn out" as occurs after deep-rooted legumes.

The possibilities for improvement of grain land in nitrogen and organic carbon has been indicated by Jones and Yates (9) and by De Turk (5). In Idaho (8) and Utah (6) experiments, growth of field peas has proved beneficial on dry-farmed soils. Wood (18) listed field peas among legumes found to gain nitrogen in excess of that supplied. Abey (1) found the nitrogen fixed by peas was greater with poor or unfertilized soil. Lyon and Wilson (10) reported that 10 years of field pea green manuring with the crop planted in July and turned under in the fall gave a loss of 380 pounds of nitrogen an acre. Mooers (11) found a slight gain in nitrogen from the second decade of green manuring with cowpeas. Austrian winter peas are being used extensively in the South Atlantic states, where they are becoming one of the most highly valued green manures (3).

It has recently been shown (13) that it is entirely practicable to improve the soil's supply of organic matter by manuring, crop rotation, and moisture control. At the Oregon Agricultural Experiment Station a definite accumulation of soil nitrogen and organic carbon has resulted in 16 years from a 3-year rotation of barley, clover, and beans grown on Amity silty clay loam. The gain in soil nitrogen was 224 pounds an acre to plow depth under rainfall farming and 380 pounds with supplemental irrigation. Manure applied at the rate of 10 tons an acre each third year resulted in a gain of 320 pounds of nitrogen without and 408 pounds with irrigation. With rotation and manure used in combination the gain in nitrogen was 544 pounds without watering and 788 pounds an acre when irrigated.

[1]Contribution from the Soils Department, Oregon Agricultural Experiment Station, Corvallis, Oregon. Published with the approval of the Director, also presented at the meeting of the Society held in Washington, D. C., November 20, 1930. Received for publication December 9, 1930.

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[3]Reference by number is to "Literature Cited," p. 387.

The increase in organic carbon was approximately 11 times as much as the nitrogen gain, though there was a tendency toward a narrowing of the nitrogen-carbon ratio with irrigation. Striking differences were found in crop yield, in returns an acre inch, in net profit an acre, and in water cost, and correlate nicely with the increase in organic carbon, soil nitrogen, and nitrate supplying power. The rotation included two legumes, with clover aftermath and bean straw turned under.

EXPERIMENTAL METHODS

The soils used in these experiments were carefully analyzed for total nitrogen at the beginning and at the close of the trial. All nitrogen-carrying materials added during the experiments were carefully analyzed, and any nitrogen fixed by non-symbiotic micro-organisms was accounted for. Two soils were used for the pot culture work, namely, Chehalis medium sandy loam from the sub-humid Willamette Valley stream bottom land, and a light, very fine, sandy loam of loessial origin from the Moro dry land experiment station in eastern Oregon. The first soil had a nitrogen content of 1,996 pounds in 2,000,000 pounds of surface soil and a pH value of 7.15, while the second contained 1,752 pounds of nitrogen and had a pH value of 7.5.

The soils were passed through a quarter inch screen and thoroughly mixed before being placed in jars. Eight treatments were used in triplicate jars of each soil, making 48 jars in all.

Series No. 1, consisting of three pots of each soil, was treated with a saturated solution of copper sulfate to check activity of non-symbiotic nitrogen-fixing micro-organisms. These pots were then covered with earthen lids during the experimental period, no water being added except that containing the copper sulfate.

Series No. 2 was fallowed.

In Series No. 3, peas were harvested.

In Series No. 4, peas were mixed with the soil after their weights were determined.

Series No. 5 received 200 pounds of ammonium phosphate containing 42 pounds of nitrogen and 100 pounds potassium sulfate per 2,000,000 pounds of soil.

Series No. 6 received potassium phosphate at the rate of 200 pounds, and potassium sulfate to the amount of 100 pounds per 2,000,000 pounds of soil.

Series No. 7 was given alfalfa tops at the rate of 3 tons an acre.

Series No. 8 received an application of 3 tons of alfalfa tops and 100 pounds of sulfur an acre.

One jar of each series from 5 to 8, inclusive, was harvested, while the peas grown on the other two were returned to the soil. The peas were harvested at blooming time, and where used for green manure, were cut up and mixed into the soil. Five crops of Austrian winter peas were grown on the Chehalis soil and four on the soil from Moro. The watering was with nitrogen-free distilled water, and was maintained within the optimum range for growth. All the pots were inoculated with the pea species *Rhizobium leguminosarum*. An abundance of root nodules developed. The crop harvested from one pot in each of series Nos. 3, 6, 7, and 8 was dried and analyzed, and the nitrogen found was credited to the pot from which it had been taken.

The modified Gunning-Hibbard method was used for making all total nitrogen determinations. Pea tops were air dried at 30° C before analyzing. Duplicate 2-gram samples of finely ground plant material were digested. An additional sample was dried at 101° C. Soil samples were ground to pass a 100-mesh sieve. For total soil nitrogen, duplicate 10-gram samples were used and were dried at 110° C. Nitrate nitrogen was included in the soil nitrogen determinations. Determinations were repeated where more than 0.2cc, or 0.0028%, or 56 pounds difference in 2,000,000 pounds of soil was observed for duplicates. Determinations on plant material were made to check within 0.05%. Blanks were run to check nitrogen that might be present in chemicals. Nitrogen-free distilled water and acid were used in all determinations.

The wet combustion method as simplified by Heck (7) was used for total carbon in soils. Checks were run for non-organic carbon.

Micro-biological examination of samples of soil revealed Azotobacter present in all except sterilized jars, yet they were inactive. One species of fungus was found to persist on the copper sulfate soil. This treated soil was found to be free from other micro-organisms.

RESULTS

YIELDS

Seeds to be planted were weighed for each crop. The first planting was in October, 1927. Table 1 gives the weight of each crop, and an average of the five crops for each treatment. Untreated pots yielded practically the same at the outset. Later, green-manured pots yielded more in every case. Results from mineral fertilizers with or without nitrogen were similar. The alfalfa tops produced lower yields than where field pea green manure was employed.

TABLE 1.—*Green weight of each pea crop grown on Chehalis soil.*

Series No.	Pot No.	Yield in grams						
		1st crop	2d crop	3d crop	4th crop	5th crop	Total	Average
3	7	20.12	91.17	37.76	54.5	67.49	271.04	54.21
	8	21.70	95.54	32.91	58.0	66.39	274.54	54.91
	9	14.33	93.75	26.58	50.7	62.23	247.59	49.52
4	10	19.26	99.48	48.28	81.0	61.04	309.06	61.81
	11	19.77	107.05	49.86	76.5	50.97	304.15	60.83
	12	21.42	118.06	40.86	87.0	59.89	327.23	65.45
5	13	22.00	124.17	46.70	59.0	66.73	298.60	59.72
	14	28.32	124.45	45.06	81.0	72.59	351.42	70.28
	15	23.15	112.48	49.57	97.5	79.87	362.57	72.51
6	16	20.31	93.11	46.77	77.0	51.74	288.93	57.99
	17	19.09	116.90	57.57	102.0	38.11	333.67	66.73
	18	17.61	100.96	46.01	89.0	59.71	313.29	62.66
7	19	25.91	97.10	41.28	43.5	54.07	261.86	52.37
	20	27.37	105.01	49.88	70.5	62.49	315.25	63.05
	21	18.86	79.72	40.76	55.0	62.39	256.73	51.35
8	22	21.86	100.56	44.83	59.0	72.77	299.02	59.80
	23	26.58	87.83	47.81	74.0	76.14	312.36	62.47
	24	23.75	86.27	40.44	52.5	74.67	277.63	55.53

TABLE 2.—*Green weight of each pea crop grown on Moro soil.*

Series No.	Pot No.	Yield in grams					
		1st crop	2d crop	3d crop	4th crop	Total	Average
3	31	106.94	36.68	34.0	55.46	233.08	58.27
	32	86.83	31.88	52.0	53.42	221.13	56.03
	33	88.08	35.48	61.5	55.80	240.86	60.22
4	34	117.39	46.26	73.5	79.76	316.91	79.23
	35	76.67	43.68	70.5	54.24	245.09	61.27
	36	86.42	40.46	70.0	68.40	265.28	66.32
5	37	74.18	37.55	41.0	47.42	200.15	50.04
	38	153.79	49.73	84.5	65.90	353.92	86.48
	39	178.51	47.58	88.5	54.20	368.79	92.20
6	40	91.20	46.18	57.0	52.00	246.38	61.60
	41	115.35	48.73	91.5	59.62	315.20	78.80
	42	79.87	44.13	86.0	35.10	245.15	61.29
7	43	147.13	46.28	56.0	46.20	295.61	73.90
	44	130.99	46.28	89.0	60.10	326.37	81.59
	45	127.80	43.62	65.0	55.10	291.52	72.88
8	46	112.07	39.18	56.5	55.44	263.19	65.80
	47	146.31	48.00	63.5	59.96	322.77	80.69
	48	102.97	39.38	50.0	27.30	219.65	54.91

TABLE 3.—*Nitrogen balance of Chehalis soil.*

Pot No.	Treatment*	N in soil, %	N content after cropping		Total N of pots at beginning of experiment, %	N gained or lost		Average N gain or loss, pounds per acre
			Removed from soil in crop, %	Soil + crop, %		%	Pounds per acre	
1	Copper sulfate saturated	0.0962	——	0.0962	0.0998	—0.0036	— 72	— 86
1a	Copper sulfate saturated	0.0948	——	0.0948	0.0998	—0.0050	—100	
2	Copper sulfate saturated	0.0950	——	0.0950	0.0998	—0.0048	— 96	— 82
2a	Copper sulfate saturated	0.0964	——	0.0964	0.0998	—0.0034	— 68	
3	Copper sulfate saturated	0.1006	——	0.1006	0.0998	+0.0008	+ 16	+ 20
3a	Copper sulfate saturated	0.1010	——	0.1010	0.0998	+0.0012	+ 24	
4	Fallow	0.1017	——	0.1017	0.0998	+0.0019	+ 38	+ 29
4a	Fallow	0.0988	——	0.0988	0.0998	—0.0010	— 20	
5	Fallow	0.1013	——	0.1013	0.0998	+0.0015	+ 30	— 6
5a	Fallow	0.0977	——	0.0977	0.0998	—0.0021	— 42	
6	Fallow	0.0985	——	0.0985	0.0998	—0.0013	— 26	— 48
6a	Fallow	0.0964	——	0.0964	0.0998	—0.0035	— 70	
7	No treatment, crop harvested	0.1076	0.0250	0.1326	0.1039	+0.0287	+574	+580
7a	No treatment, crop harvested	0.1085	0.0249	0.1332	0.1039	+0.0293	+586	
8	No treatment, crop harvested	0.1056	0.0250	0.1306	0.1038	+0.0268	+536	+536
8a	No treatment, crop harvested	0.1058	0.0249	0.1306	0.1038	+0.0268	+536	
9	No treatment, crop harvested	0.1067	0.0240	0.1307	0.1037	+0.0270	+540	+564
9a	No treatment, crop harvested	0.1093	0.0240	0.1331	0.1037	+0.0294	+588	
10	No treatment, crop returned to soil	0.1198	——	0.1198	0.1038	+0.0160	+320	+346
10a	No treatment, crop returned to soil	0.1224	——	0.1224	0.1038	+0.0186	+372	
11	No treatment, crop returned to soil	0.1215	——	0.1215	0.1037	+0.0178	+356	+337
11a	No treatment, crop returned to soil	0.1196	——	0.1196	0.1037	+0.0159	+318	
12	No treatment, crop returned to soil	0.1271	——	0.1271	0.1038	+0.0233	+466	+488
12a	No treatment, crop returned to soil	0.1293	——	0.1293	0.1038	+0.0255	+510	

13	200 lbs. $(NH_4)_2HPO_4$+100 lbs K_2SO_4,	0.1087	0.0291	0.1378	0.1058	+0.0320	+640	+643
13a	crop harvested.	0.1088	0.0293	0.1381	0.1058	+0.0323	+646	
14	200 lbs. $(NH_4)_2HPO_4$+100 lbs. K_2SO_4,	0.1221	——	0.1221	0.1060	+0.0161	+322	+328
14a	crop returned to soil.	0.1227	——	0.1227	0.1060	+0.0167	+334	
15		0.1268	——	0.1268	0.1060	+0.0208	+416	+402
15a		0.1254	——	0.1254	0.1060	+0.0194	+388	
16	200 lbs. K_2HPO_4+100 lbs. K_2SO_4,	0.1087	0.0243	0.1330	0.1039	+0.0291	+582	+570
16a	crop harvested.	0.1072	0.0246	0.1318	0.1039	+0.0279	+558	
17	200 lbs. K_2HPO_4+100 lbs. K_2SO_4,	0.1229	——	0.1229	0.1036	+0.0193	+386	+372
17a	crop returned to soil.	0.1215	——	0.1215	0.1036	+0.0179	+358	
18		0.1256	——	0.1256	0.1040	+0.0216	+432	+408
18a		0.1232	——	0.1232	0.1040	+0.0192	+384	
19	3 tons alfalfa tops, crop harvested.	0.1096	0.0226	0.1322	0.1110	+0.0211	+422	+415
19a		0.1090	0.0225	0.1315	0.1111	+0.0204	+408	
20	3 tons alfalfa tops, crop returned to soil	0.1228	——	0.1228	0.1110	+0.0118	+236	+209
20a		0.1201	——	0.1201	0.1110	+0.0091	+182	
21		0.1231	——	0.1231	0.1111	+0.0120	+240	+236
21a		0.1227	——	0.1227	0.1111	+0.0116	+232	
22	3 tons alfalfa tops+100 lbs. sulfur,	0.1087	0.0232	0.1319	0.1109	+0.0210	+420	+399
22a	crop harvested.	0.1067	0.0231	0.1298	0.1109	+0.0189	+378	
23a	3 tons alfalfa tops+100 lbs. sulfur,	0.1235	——	0.1235	0.1109	+0.0126	+252	+238
23a	crop returned to soil.	0.1221	——	0.1221	0.1109	+0.0112	+224	
24	Crop returned to soil.	0.1234	——	0.1234	0.1110	+0.0124	+248	+262
24		0.1248	——	0.1248	0.1110	+0.0138	+276	

*Treatments given in quantities per acre.

The Moro soil pots were started in early spring 1928, and the higher yields obtained are due to all pots of both soils being placed out doors during the growth period. The results given in Table 2 show a higher average yield on the three pots in which peas were used as green manure. Chemical fertilizers resulted in slight increases in yield.

NITROGEN IN THE CROPS HARVESTED

There was very little difference in the nitrogen content of the five crops due to the treatments, hence the data are omitted to save space. There was approximately 1% more nitrogen in crops grown on the Chehalis soil, which has a higher nitrogen content, than on the Moro soil. The average nitrogen content of peas grown on Chehalis soil was 3.56%, while for the Moro soil it was 2.55%.

NITROGEN BALANCE

The last crop grown on the pots was turned under, and after it was well decomposed representative soil samples were taken from each pot, air dried, and total nitrogen determinations made.

Growing five crops of peas on Chehalis soil resulted in a definite gain in soil nitrogen in all cropped pots (Table 3). Sterilized and fallowed pots appear to have lost nitrogen. Pots from which crops were harvested, when nitrogen removed by the crop was accounted

TABLE 4.—*Nitrogen balance of Chehalis soil, crops harvested.*

Pot No.	Treatment*	N content of soil after cropping, %	N content of soil at beginning, %	N gained or lost		Average N gain or loss, pounds per acre
				%	Pounds per acre	
7	None	0.1076	0.1039	+0.0037	+74	+83
7	None	0.1085	0.1039	+0.0046	+92	
8	None	0.1056	0.1038	+0.0018	+36	+38
8	None	0.1058	0.1038	+0.0020	+40	
9	None	0.1067	0.1037	+0.0030	+60	+86
9	None	0.1093	0.1037	+0.0056	+112	
13	200 lbs. $(NH_4)_2HPO_4$........	0.1087	0.1058	+0.0029	+58	+59
13	+100 lbs. K_2SO_4..	0.1088	0.1058	+0.0030	+60	
16	200 lbs. K_2HPO_4+	0.1087	0.1039	+0.0048	+96	+81
16	100 lbs. K_2SO_4....	0.1072	0.1039	+0.0033	+66	
19	3 tons alfalfa tops	0.1096	0.1111	—0.0015	—30	—36
19		0.1090	0.1111	—0.0021	—42	
22	3 tons alfalfa tops	0.1087	0.1109	—0.0022	—44	—64
22	+100 lbs. sulfur	0.1067	0.1109	—0.0042	—84	

*Treatments given in quantities per acre.

for, showed by a wide margin the greatest amount of nitrogen fixed. These increases ranged from 200 to 250 pounds of nitrogen an acre. Without taking the nitrogen in the crop into account, there was very little gain in soil nitrogen, and with alfalfa additions there was a loss.

Table 4 gives the nitrogen balance of the soil at the conclusion of the experiment on pots which were cropped and the crop all removed.

Crop and soil samples were handled as above with Moro soil and the data shown in Table 5. Here, also, a positive gain in soil nitrogen resulted from four crops of field peas, while sterilized and fallow pots showed a loss. The total nitrogen balance was higher for crop and soil where harvesting was practiced.

The nitrogen balance for Moro soil pots from which peas were harvested is given in Table 6. Pots receiving nitrogen in the form of fertilizer gave a decrease.

ORGANIC CARBON

Total organic carbon analyses were made to determine changes in organic matter content induced by cropping to peas. The organic matter content was obtained by multiplying the organic carbon by the factor 1.724. This factor, while only approximate, was found to be satisfactory by Sievers and Holtz (16).

The initial N:C ratio for the Chehalis soil (Table 7) was 1:11.14, and for the Moro soil (Table 8), 1:11.30. Soil building treatments tended to narrow this ratio, especially field pea green manuring. Alfalfa green manure did not change the N:C ratio materially.

A summary is presented (Table 9) which shows substantial increases in nitrogen and organic carbon contents of the soils when Austrian winter peas were grown as a green manure crop. Where peas were harvested the nitrogen fixed, or the nitrogen accounted for in the soil plus that removed in the crop, was even greater than when the peas were used as a cover crop. The nitrogen content of the soil was changed but little when the crop was removed. Chehalis soil showed an increase for all treatments, except alfalfa tops, while the Moro soil showed a decrease for all except untreated pots. The gain in nitrogen fixed varied from approximately 300 to 500 pounds per acre.

DISCUSSION

Where peas were turned under the activity of micro-organisms in fixing nitrogen seemed to be lessened. These results are contrary to those of Albrecht (2). However, in his experiment, a soil of very low nitrogen content was used. The average gain in nitrogen, including

TABLE 5.—*Nitrogen balance, Moro soil.*

Pot No.	Treatment*	N in soil, %	N content after cropping: Removed from soil in crop, %	N content after cropping: Soil + crop, %	Total N of pots at beginning of experiment, %	N gained or lost: %	N gained or lost: Pounds per acre	Average N gain or loss, pounds per acre
25	Copper sulfate saturated	0.0861	——	0.0861	0.0876	—0.0015	— 30	— 54
25a	Copper sulfate saturated	0.0837	——	0.0837	0.0876	—0.0039	— 78	
26	Copper sulfate saturated	0.0854	——	0.0854	0.0876	—0.0022	— 44	— 57
26a	Copper sulfate saturated	0.0841	——	0.0841	0.0876	—0.0035	— 70	
27	Copper sulfate saturated	0.0852	——	0.0852	0.0876	—0.0024	— 48	— 57
27a	Copper sulfate saturated	0.0843	——	0.0843	0.0876	—0.0033	— 66	
28	Fallow	0.0861	——	0.0861	0.0876	—0.0015	— 30	— 54
28a	Fallow	0.0837	——	0.0837	0.0876	—0.0039	— 78	
29	Fallow	0.0857	——	0.0857	0.0876	—0.0019	— 38	— 54
29a	Fallow	0.0841	——	0.0841	0.0876	—0.0035	— 70	
30	Fallow	0.0826	——	0.0826	0.0876	—0.0050	—100	— 96
30a	Fallow	0.0830	——	0.0830	0.0876	—0.0046	— 92	
31	No treatment, crop harvested	0.0916	0.0239	0.1155	0.0915	+0.0240	+480	+476
31a	No treatment, crop harvested	0.0909	0.0242	0.1151	0.0915	+0.0236	+472	
32	No treatment, crop harvested	0.0918	0.0194	0.1112	0.0915	+0.0197	+394	+396
32a	No treatment, crop hravested	0.0919	0.0195	0.1114	0.0915	+0.0199	+398	
33	No treatment, crop harvested	0.0940	0.0213	0.1153	0.0915	+0.0238	+476	+445
33a	No treatment, crop harvested	0.0909	0.0213	0.1122	0.0915	+0.0207	+414	
34	No treatment, crop returned to soil	0.1126	——	0.1125	0.0915	+0.0210	+420	+411
34a	No treatment, crop returned to soil	0.1116	——	0.1116	0.0915	+0.0201	+402	
35	No treatment, crop returned to soil	0.1122	——	0.1122	0.0915	+0.0207	+414	+391
35a	No treatment, crop returned to soil	0.1099	——	0.1099	0.0915	+0.0184	+368	
36	No treatment, crop returned to soil	0.1105	——	0.1105	0.0915	+0.0190	+380	+383
36a	No treatment, crop returned to soil	0.1108	——	0.1108	0.0915	+0.0193	+386	
37	200 lbs. $(NH_4)_2HPO_4$ + 100 lbs. K_2SO_4, crop harvested	0.0889	0.0194	0.1083	0.0936	+0.0147	+294	+268
37a		0.0866	0.0191	0.1057	0.0936	+0.0121	+242	

38	200 lbs. $(NH_4)_2HPO_4$+100 lbs. K_2SO_4,	0.1162	——	0.1162	0.0936	+0.0226	+452	+448
38a	crop returned to soil	0.1158	——	0.1158	0.0936	+0.0222	+444	
39		0.1166	——	0.1166	0.0936	+0.0230	+460	+485
39a		0.1191	——	0.1191	0.0936	+0.0255	+510	
40	200 lbs. K_2HPO_4+100 lbs. K_2SO_4,	0.0906	0.0241	0.1147	0.0915	+0.0232	+464	+445
40a	crop harvested	0.0889	0.0239	0.1128	0.0915	+0.0213	+426	
41	200 lbs. K_2HPO_4+100 lbs. K_2SO_4,	0.1129	——	0.1129	0.0915	+0.0214	+428	+423
41a	crop returned to soil	0.1124	——	0.1124	0.0915	+0.0209	+418	
42		0.1062	——	0.1062	0.0915	+0.0147	+294	+296
42a		0.1064	——	0.1064	0.0915	+0.0149	+298	
43	3 tons alfalfa tops, crop harvested	0.0943	0.0293	0.1236	0.0992	+0.0244	+488	+489
43a		0.0940	0.0297	0.1237	0.0992	+0.0245	+490	
44	3 tons alfalfa tops, crop returned to	0.1194	——	0.1194	0.0992	+0.0202	+404	+378
44a	soil	0.1168	——	0.1168	0.0992	+0.0176	+352	
45		0.1116	——	0.1116	0.0992	+0.0124	+248	+276
45a		0.1144	——	0.1144	0.0992	+0.0152	+304	
46	3 tons alfalfa tops+100 lbs. sulfur,	0.0940	0.0234	0.1174	0.0992	+0.0182	+364	+356
46a	crop harvested	0.0930	0.0235	0.1166	0.0992	+0.0174	+348	
47	3 tons alfalfa tops+100 lbs. sulfur,	0.1190	——	0.1190	0.0992	+0.0198	+396	+416
47a	crop returned to soil	0.1210	——	0.1210	0.0992	+0.0218	+436	
48		0.1053	——	0.1053	0.0992	+0.0061	+122	+129
48a		0.1060	——	0.1060	0.0992	+0.0068	+136	

*Treatments given in quantities per acre.

TABLE 6.—*Nitrogen balance of Moro soil, crops harvested.*

Pot No.	Treatment*	N content of soil after cropping, %	N content of soil at beginning, %	N gained or lost		Average N gain or loss, pounds per acre
				%	Pounds per acre	
31	None	0.0916	0.0915	+0.0001	+ 2	— 5
31	None	0.0909	0.0915	—0.0006	— 12	
32	None	0.0918	0.0915	+0.0003	+ 6	+ 7
32	None	0.0919	0.0915	+0.0004	+ 6	
33	None	0.0940	0.0915	+0.0025	+ 50	— 19
33	None	0.0909	0.0915	—0.0006	— 12	
37	200 lbs. $(NH_4)_2$-HPO_4	0.0889	0.0936	—0.0047	— 94	—117
37	+100 lbs. K_2SO_4	0.0866	0.0936	—0.0070	—140	
40	200 lbs. K_2HPO_4+	0.0906	0.0915	—0.0006	— 12	— 32
40	100 lbs. K_2SO_4	0.0889	0.0915	—0.0026	— 52	
45	5 tons alfalfa tops	0.0943	0.0992	—0.0046	— 92	— 98
45		0.0940	0.0992	—0.0052	—104	
46	3 tons alfalfa tops	0.0940	0.0992	—0.0052	—104	—114
46	+100 lbs. sulfur	0.0950	0.0992	—0.0062	—124	

*Treatments given in quantities per acre.

TABLE 7.—*The effect of Austrian winter peas on organic carbon content and N:C ratio of Chehalis soil.*

Pot No.	Treatment*	Organic matter (approximate) %	Organic C, %	Average organic C, %	N, %	N:C ratio
	Initial soil	1.917	1.112	1.112	0.0998	1:11.14
1	Saturated copper sulfate	1.873	1.086			
1	Saturated copper sulfate	1.765	1.024	1.065	0.0955	1:11.04
2	Saturated copper sulfate	1.864	1.081			
2	Saturated copper sulfate	1.836	1.065	1.073	0.0957	1:11.21
3	Saturated copper sulfate	1.846	1.071			
3	Saturated copper sulfate	1.886	1.095	1.083	0.1008	1:10.74
4	Fallow	1.708	0.991			
4	Fallow	1.828	1.060	1.026	0.1003	1:10.24
5	Fallow	1.859	1.078			
5	Fallow	1.940	1.125	1.102	0.0995	1:11.08
6	Fallow	1.890	1.096			
6	Fallow	1.834	1.064	1.080	0.0975	1:11.08
7	None, crop harvested	1.850	1.073			
7	None, crop harvested	1.855	1.076	1.075	0.1081	1: 9.95
8	None, crop harvested	2.053	1.196			
8	None, crop harvested	1.954	1.133	1.165	0.1057	1:11.02
9	None, crop harvested	1.866	1.083			
9	None, crop harvested	1.956	1.135	1.109	0.1080	1:10.26

*Treatments given in quantities per acre.

TABLE 7.—*Concluded*

Pot No.	Treatment*	Organic matter (approximate) %	Organic C, %	Average organic C, %	N, %	N:C ratio
10	None, crop returned to soil . .	2.089	1.211			
10	None, crop returned to soil . .	2.216	1.285	1.248	0.1211	1:10.30
11	None, crop returned to soil . .	2.135	1.238			
11	None, crop returned to soil . .	2.183	1.286	1.252	0.1206	1:10.38
12	None, crop returned to soil . .	2.111	1.225			
12	None, crop returned to soil . .	2.187	1.268	1.247	0.1282	1: 9.73
13	200 lbs. $(NH_4)_2HPO_4$+100	1.868	1.084			
13	lbs. K_2SO_4, crop harvested	1.920	1.114	1.099	0.1088	1:10.10
14	200 lbs. $(NH_4)_2HPO_4$, + ...	2.071	1.201			
14	100 lbs. K_2SO_4, crop returned	1.985	1.151	1.176	0.1224	1: 9.63
15	to soil.	2.010	1.165			
15		2.038	1.182	1.174	0.1261	1: 9.31
16	200 lbs. K_2HPO_4+100 lbs.	1.894	1.098			
16	K_2SO_4, crop harvested.	1.841	1.068	1.083	0.1080	1:10.02
17	200 lbs. K_2HPO_4+ 100 lbs.	2.072	1.202			
	K_2SO_4, crop returned to	2.047	1.186	1.194	0.1222	1: 9.77
18	soil	2.155	1.250	1.232	0.1244	1: 9.91
18		2.092	1.214			
19	3 tons alfalfa tops, crop harvested	2.009	1.165	1.154	0.1093	1:10.55
19		1.969	1.142			
20	3 tons alfalfa tops, crop returned to soil	2.014	1.168	1.171	0.1215	1: 9.65
20		2.023	1.174			
21		2.207	1.280	1.261	0.1229	1:10.26
21		2.141	1.242			
22	3 tons alfalfa tops, crop harvested	2.054	1.191	1.171	0.1077	1:10.87
22		1.984	1.150			
23	3 tons alfalfa tops+100 lbs.	2.200	1.276	1.281	0.1228	1:10.43
23	sulfur, crop returned to	2.216	1.285			
24	soil	2.205	1.279	1.268	0.1241	1:10.21
24		2.167	1.256			

*Treatments given in quantities per acre.

that in the harvested crop, was 44 pounds more for harvested pots of Moro soil and 200 pounds an acre to plow depth based on the Chehalis soil pots. The Chehalis soil when green manured with field peas showed 82 pounds nitrogen fixed per acre for each crop, while the Moro soil showed a corresponding gain of 96 pounds. Growth and harvest of peas left a larger nitrogen supply in Chehalis soil, although with the Moro soil the supply was slightly reduced. The nitrogen content of crops removed does not explain this, for it was higher with peas grown on Chehalis soil in every case. The four crops grown on

TABLE 8.—*The effect of Austrian winter peas on organic matter content and N:C ratio of Moro soil.*

Pot No.	Treatment*	Organic matter (approximate) %	Organic C, %	Average organic C, %	N, %	N:C ratio
	Initial soil	1.707	0.960	0.090	0.0876	1:11.30
25	Saturated copper sulfate	1.645	0.954	0.943	0.0849	1:11.10
25	Saturated copper sulfate	1.605	0.931			
26	Saturated copper sulfate	1.665	0.966	0.958	0.0848	1:11.29
26	Saturated copper sulfate	1.637	0.950			
27	Saturated copper sulfate	1.607	0.933	0.945	0.0868	1:11.14
27	Saturated copper sulfate	1.648	0.956			
28	Fallow	1.596	0.924	0.919	0.0849	1:10.75
28	Fallow	1.553	0.901			
29	Fallow	1.643	0.953	0.945	0.0849	1:11.13
29	Fallow	1.614	0.936			
30	Fallow	1.558	0.904	0.900	0.0628	1:10.66
30	Fallow	1.543	0.895			
31	None, crop harvested	1.696	0.984	0.980	0.0913	1:10.73
31	None, crop harvested	1.682	0.976			
32	None, crop harvested	1.786	1.036	1.042	0.0919	1:11.34
32	None, crop harvested	1.806	1.046			
33	None, crop harvested	1.734	1.000	1.013	0.0925	1:10.95
33	None, crop harvested	1.769	1.026			
34	None, crop returned to soil	1.907	1.106			
34	None, crop returned to soil	1.914	1.111	1.109	0.1121	1: 9.69
35	None, crop returned to soil	1.954	1.134			
35	None, crop returned to soil	1.942	1.126	1.130	0.1111	1:10.16
36	None, crop returned to soil	1.922	1.115			
36	None, crop returned to soil	1.907	1.106	1.111	0.1107	1:10.04
37	300 lbs. $(NH_4)_2HPO_4$+100	1.714	0.994	1.025	0.0873	1:11.67
37	lbs. K_2SO_4, crop harvested	1.820	1.055			
38	300 lbs. $(NH_4)_2HPO_4$+ 100	1.983	1.150	1.143	0.1160	1: 9.85
38	lbs. K_2SO_4, crop returned	1.957	1.135			
39	to soil	2.014	1.168	1.172	0.1179	1: 9.95
39		2.027	1.175			
40	200 lbs. K_2HPO_4+100 lbs.	1.679	0.974	0.986	0.0898	1:10.98
40	K_2SO_4, crop harvested	1.720	0.998			
41	200 lbs. K_2HPO_4+100 lbs.	1.937	1.124	1.058	0.1127	1: 9.65
41	K_2SO_4, crop returned to	1.612	1.051			
42	soil	1.970	1.143	1.135	0.1063	1:10.68
42		1.944	1.127			
43	3 tons alfalfa tops, crop har-	1.607	1.048	1.076	0.0942	1:11.43
43	vested	1.902	1.103			
44	3 tons alfalfa tops, crop re-	2.098	1.216	1.195	0.1181	1:10.11
44	turned to soil	2.027	1.175			
45		1.957	1.135	1.100	0.1130	1: 9.73
45		1.636	1.065			

*Treatments given in quantities per acre.

TABLE 8.—*Continued.*

Pot No.	Treatment*	Organic matter (approximate) %	Organic C, %	Average organic C, %	N, %	N:C ratio
46	3 tons alfalfa tops, crop harvested	1.650	1.073	1.071	0.0935	1:11.46
46		1.843	1.069			
47	3 tons alfalfa tops + 100 lbs. sulfur, crop returned to soil	2.204	1.278	1.241	0.1200	1:10.34
47		2.076	1.204			
48		1.979	1.148	1.129	0.1057	1:10.68
48		1.915	1.110			

*Treatments given in quantities per acre.

TABLE 9.—*Gain or loss in nitrogen and N:C ratio.*

Treatment	Chehalis soil		Moro soil	
	N, pounds, per acre	N:C ratio	N, pounds, per acre	N:C ratio
Initial soil	——	1:11.14	——	1:11.30
Sterilized with $CuSo_4$	− 49	1:11.00	− 56	1:11.18
Fallow	− 8	1:10.78	− 88	1:10.91
No treatment, crop harvested	+560	1:10.41	+439	1:11.01
No treatment, crop returned to soil	+390	1:10.12	+394	1:10.04
200 lbs. $(NH_4)_2HPO_4$ + 100 lbs. K_2SO_4	+458	1: 9.66	+400	1:10.38
200 lbs. K_2HPO_4 + 100 lbs. K_2SO_4	+450	1: 9.90	+388	1:10.40
3 tons alfalfa tops	+287	1:10.14	+381	1:10.36
3 tons alfalfa tops + 100 lbs. sulfur	+300	1:10.49	+300	1:10.78
Average of six treatments	+408	1:10.68	+384	1:10.15
Average of six treatments per crop	+ 82	1:10.68	+ 96	1:10.15
Average all pots with crop harvested	+530	1:10.40	+411	1:11.22
Average all pots with crops returned to soil	+330	1: 9.96	+367	1:10.08

Moro soil yielded dry matter almost equal to the five crops grown on Chehalis soil.

No treatment employed affected the nitrogen supply significantly through its effect on non-symbiotic nitrogen-fixing organisms. All nitrogen won may be credited to symbiotic fixation. Abey (1) found similar results in fallow soils.

The effect on the organic carbon of the soil was very similar to that on the nitrogen. Turning under peas narrowed the N: C ratio in every case.

Greenhouse experiments as herein described are usually conducted with artificial watering to maintain soil moisture within the optimum range. Clean cultivated fallow is the chief means of moisture control on the dry farm. Well-rotted manure fallowed in and followed

by a vigorous feeding crop like corn has been a successful practice at the Moro station. The crop-producing power of a milligram of nitrate has been found to be approximately twice as great as that of a milligram of other "essential" nutrients, when used with seedlings under controlled conditions (15). The water requirement has been greatly reduced where nitrate and organic carbon were maintained (14). Soil fertility and moisture go hand in hand.

There are several reasons why moisture control in semi-arid soils facilitates maintaining or increasing the soil's supply of nitrogen and organic carbon. Excessive soil aeration is avoided and temperature modified. The rather general calcareous character of western soils favors maintaining a good supply of soil organic matter with moisture control. A larger aftermath or crop residue forms for incorporation into soil with late season moisture provided. Supplemental irrigation in sub-humid climates, especially in connection with sewage disposal, is a promising means of increasing soil organic matter. The advantages thereof are discussed elsewhere (13).

SUMMARY

1. The growth of Austrian winter peas as a green manure crop increased the nitrogen and the organic matter content of the soil. The good supply of calcium in soils used, as well as moisture control, contributed to the results.

2. The total nitrogen of the soil remained unchanged when the crop was harvested and removed in all cases except where alfalfa tops were used as a fertilizer material. In this case there was a slight decrease in the nitrogen balance of the soil.

3. The total nitrogen balance where peas were grown and harvested, including nitrogen in the crop, was higher than where peas were grown and turned under.

4. The nitrogen content in the tops was highest in peas grown on the soil containing the higher nitrogen content.

5. Changes in the organic carbon content of the soil tended to vary with those of the nitrogen content where the peas were either harvested or used as a green manure crop. However, the turning under of the pea crop tended to narrow the nitrogen-carbon ratio of the soil.

6. The addition of alfalfa tops to the soils decreased the amount of nitrogen fixed by the pea crop, but helped to maintain the nitrogen-carbon ratio more nearly like that of the initial soil.

7. A saturated solution of copper sulfate added to the soil proved toxic to all soil organisms, except one type of fungus. This one per-

sisted when in direct contact with crystals of copper sulfate. The fallow soils showed no increase in nitrogen content, although Azotobacter were present. The change in nitrogen content from that of the initial soil was practically the same in fallow and in copper sulfate treated soils.

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BREEDING FOR YIELD IN CROP PLANTS[1]

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Seed yield is perhaps the most important quality of the cereal crops. Variety tests are conducted at almost every experiment station for the purpose of determining the highest yielding varieties. New strains developed by the plant breeder are carried through a long series of nursery and field plat yield tests, and their value for distribution hinges on their ranking in yield with the best of the standard local sorts. There are, of course, other characters that are always considered in the rating of a variety, such as disease resistance, erectness, winter hardiness; but they affect yield indirectly and are called ancillary characters by Engledow and Ramiah (2).[3]

The present situation with regard to breeding for yield in the cereal crops cannot be considered satisfactory. Too little information is available relative to the internal yield factors of our common strains. When, in plat tests, variety A exceeds variety B, we do not know why. Is it because of a difference in number of plants per unit area, which in turn is the result of a difference in size of seed in the two varieties? Or is it because of the ability of variety A to stool better under the same conditions than variety B and thus produce a larger number of heads per unit area? Such questions as these suggest the kind of information that we need about strains, but that we do not have at present.

Seed yield is a very complex character. It is the end result and sum total of the activities of the plant. Two main forces determine the amount of seed produced. These are environment and heredity. Soil type, soil fertility, moisture, and temperature are examples of environmental influences. Inherent influences or factors are important also, because we know that certain varieties yield better than others—though tested under the same environmental conditions. This paper deals with the inherent factors affecting seed yield in a few self-fertilized crops, such as wheat, oats, barley, and soybeans.

[1]Contribution from the Division of Plant Breeding, Dept. of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Also presented as part of the symposium on "Plant Breeding" at the meeting of the Society held in Washington, D. C., November 20, 1930. Received for publication December 8, 1930.

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[3]Reference by number is to "Literature Cited," p. 395.

YIELD ATTRIBUTES

On account of the complexity of seed yield as a plant character, it is very difficult to study. It must be made relatively simpler by breaking it down into its component parts and studying each part separately, as well as in combination with each of the other parts. The component parts are also complex and do not lend themselves readily to genetic analysis. This is because they are quantitative in nature with a complicated mode of inheritance and are affected more or less by environmental influences. The complexity of each component or attribute further emphasizes the complexity of yield which is the result of all components working together.

The component parts or attributes which make up yield vary, of course, with the crop. In small grains, seed yield is determined by the number of plants per unit area, number of heads per plant, yield per head, and weight of kernel. When varieties are space-planted, and each plant has the same opportunity for development, then the number of plants per unit area, being the same for all varieties, ceases to be a variable, and can be omitted from consideration. Under drill conditions, however, the number of plants per unit of drill row becomes an important attribute of yield, and is so considered by Engledow and others who have used drill plantings for yield studies.

In the soybean, yield is determined by number of nodes per plant, number of pods per node, number of seeds per pod, percentage of undeveloped or abortive seed, and weight of seed. As in the case of small grains, number of plants per unit area or per unit of drill row also must be considered along with the other attributes mentioned when yield studies are made from drill, rather than from space, plantings.

Most of the investigators who have studied the internal yield factors of small grains have considered them in relation to the environment. Thus, Kiesselbach and Sprague (5) studied the relation of the development of the wheat spike to environmental factors. Sprague (7) dealt with correlations between yield components or attributes and yield within the same variety. Quisenberry (6) calculated correlations between plant characters and yield from samples collected from farmers' fields located in different states. Such correlations may be thought of as non-genetic, since they are the result of variations brought about by the conditions of growth and development.

EVALUATION OF STRAINS WITH RESPECT TO YIELD ATTRIBUTES

The information which would seem to be of most value from a plant breeding standpoint is that gained from a careful comparison of several types or varieties with respect to the yield attributes mentioned above. Engledow and his associates, in a number of brilliantly executed experiments, have compared and contrasted three important British wheat varieties, namely, Squarehead's Master, Yeoman, and Rivet. As a result of four years' study, the authors (2) were able to rank these varieties with respect to the various yield attributes. Rivet was superior in average yield per plant, average yield per head, weight per 1,000 kernels, and average number of grains per head and per plant, but inferior in number of heads per plant. Squarehead's Master and Yeoman were quite similar in all attributes, though the former was slightly superior in all but number of heads per plant, this being the character in which Yeoman excelled both the other varieties.

Similar data were published by Waldron (8) on a number of common and durum wheats grown at Fargo and Langdon, North Dakota. Though the data for each variety are based only on single yard-row samples, striking differences are apparent, not only in yield but in yield attributes, such as number of stools per plant, weight of 1,000 kernels, kernels per spikelet, and the like. Sprague (7) made a careful study of Red Rock and Kanred wheat grown at New Brunswick, New Jersey, and of Kanred and Turkey Red (Neb. 60) grown in Nebraska. Grantham (3) reported on the occurrence of sterile spikelets in 188 varieties of wheat grown at the Delaware Station in 1915. The range in percentage of sterile spikelets was quite marked. Some varieties had several times as many sterile spikelets as others when the plants were grown in hills 6 inches apart each way. Two years later Grantham (4) published extensive data on a large number of wheat varieties with respect to tillers per plant, yield per plant, and number of kernels in 5 grams of seed which is a measure of weight of kernel. Such data are very valuable to the plant breeder as they enable him to evaluate each variety with respect to yield attributes, and, consequently, to indicate why one variety is a better yielder than another.

In order, however, for this information to be reliable, the varieties must be so planted as to make the conditions of growth and development the same for each. If this is done, then the question of environmental influences can be left out of consideration. In studies of this kind at the Illinois Agricultural Experiment Station, on the small grain crops and soybeans, the material has been space-planted,

replicating each variety 12 to 15 times, with 12 plants in each replication, the 10 inner plants of which are harvested for study, using the outer plants at the ends of each replication as guard or border plants (Fig. 1). The plan has been to secure from each variety at least 100 plants that have had strictly comparable conditions of growth and development, and that, therefore, can be intensively and individually studied with respect to yield attributes. The mean of these 100

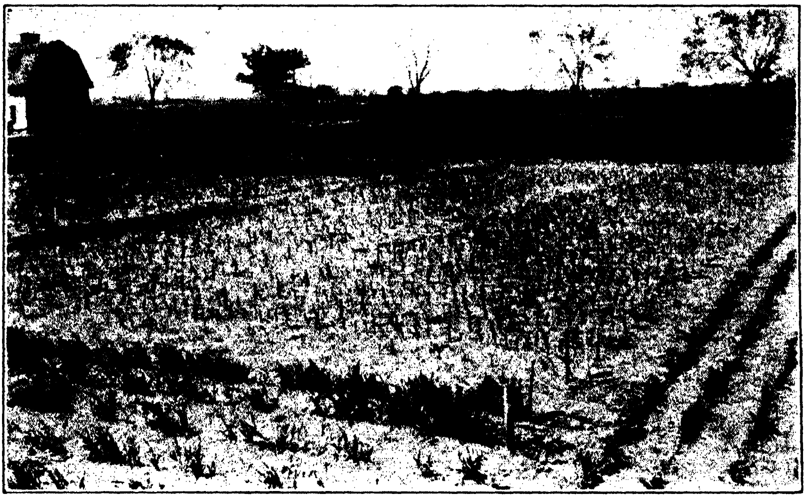

FIG. 1.—Planting of oat varieties for yield analysis studies.

plants for each yield attribute can then be determined, together with its probable error, and the variety can be compared statistically with any other variety in the experiment, and rated accordingly.

Though the experiments have just begun, certain very interesting and important facts have been learned. It has been found (1) that Spartan barley stools much better and has a heavier kernel, but has a much smaller head, than Wisconsin Pedigree or Velvet. A yield analysis of different varieties of oats is being attempted. Kanota is the lowest of those varieties under study in percentage of sterility or blight; Great Avalanche, the highest. Great Avalanche is the lowest in number of stools per plant, but it has a very large grain. Twenty-six varieties of soybeans were grown this year according to the plan above outlined, and are being evaluated for various yield factors. Striking varietal differences are apparent in number of nodes per plant, proportion of three- or four-seeded pods, percentage of abortive seeds, and size of seed.

GENETIC CORRELATION BETWEEN YIELD ATTRIBUTES AND YIELD

The next problem is the extent to which the various yield attributes are correlated with yield. Here, obviously, the plant breeder is not helped much by correlations calculated on plants within the same variety, or by what were referred to above as non-genetic correlations. Such correlations are due to concomitant variation in two characters, both of which vary as a result of the same cause, such as soil fertility; and since environmental variations are not inherited, the plant breeder cannot use them for purposes of selection. If, however, it is found that high-stooling varieties are good yielders and low-stooling varieties are poor yielders, as a rule, a knowledge of this fact is of material benefit to the plant breeder, and he can make use of it in selection. Such a relationship may be thought of as a physiologic or genetic correlation between stools and yield. Obviously, the correlation cannot be perfect because of other attributes, such as yield per head and weight of kernel. A variety may rank high in number of stools per plant but rank low in yield per head, and its yield may be no higher than that of another variety that ranks low in number of stools but high in yield per head. Genetic correlations should indicate the relative importance of the several yield attributes in producing yield, and the attribute or attributes upon which most attention should be placed by the plant breeder.

Waldron (8) has calculated genetic correlations between yield attributes and yield on the wheat varieties mentioned above. These are given in Table 1. The correlations calculated on Fargo-grown material agree fairly well with those calculated on material grown at Langdon, except in the case of kernels per spike and yield ($.73 \pm .07$, Langdon; $-.18 \pm .13$, Fargo). Waldron explains this discrepancy by the fact that at Fargo many strains lodged badly, resulting in shrinkage of kernel and hence in lower yield. Contrary to expectation, the correlation between stools per plant and yield was not significant statistically. On the other hand, kernels per spike and weight per 1,000 kernels showed high correlations with yield, with the exception noted above in the case of Fargo-grown material. The number of strains used in these experiments was 19 at Langdon and 27 at Fargo. A correlation of $.832 \pm .0256$ was calculated between number of tillers per plant and quantity of grain per plant, using Grantham's (4) data involving 66 strains. Obviously, the larger the number of different strains used in calculating genetic correlations, the more reliable the coefficients obtained; while another important consideration is that the strains be grown in such a way that environmental influences are the same for each.

TABLE 1.—*Correlations in wheat, Waldron's data.*

	Yield		Kernels per spike		Weight per 1,000 kernels	
	Langdon	Fargo	Langdon	Fargo	Langdon	Fargo
Kernels per spike	.73±.07	—.18±.13				
Weight per 1,000 kernels	.69±.08	.76±.05	.40±.13	—.29±.12		
Stools per plant	.16±.13	.25±.12	.16±.15	—.56±.09	.28±.14	.50±.10

GENETIC CORRELATIONS BETWEEN THE YIELD ATTRIBUTES

Another very important problem which concerns the plant breeder is the correlation between the yield attributes themselves. To what extent, for example, do stools per plant and size of head go together in inheritance? Can high number of stools of one variety be combined with high head yield of another variety, or must we always be content with a compromise? Varietal evaluation with respect to yield components shows that no variety ranks first in all. The usual situation is that a variety ranks well in one or more attributes, but low or medium in others. For example, the Illini soybean has a high proportion of three-seeded pods, but has a high percentage (22% in 1929) of abortive or undeveloped seed. A strain designated A. K. 114, on the other hand, has a much lower proportion of three-seeded pods and a much lower percentage of abortive seed (15% in 1929). What are the chances of isolating, from a cross between them, a type combining a high proportion of three-seeded pods with a low percentage of abortive seed? If these yield attributes are independent in inheritance, the chances should be good of securing this particular recombination type. But if they are associated and tend to stay together in the same way they are in the parents, rather than to assort independently, the probability is lessened of obtaining the desired combination. The problem, then, is to determine to what extent the yield attributes are correlated with each other.

Using Waldron's data on wheat varieties, correlations were calculated between the yield attributes stools per plant, weight of 1,000 kernels, and kernels per spike. The coefficients are given in Table 1. As in the case of correlations between these characters and yield, there are certain discrepancies which can probably be explained, as before, by the excessive lodging and consequent shrinkage of grain at Fargo. If we omit from consideration the correlations calculated on the Fargo-grown material, the following coefficients on the Langdon material are of interest:

(a) weight per 1,000 kernels and kernels per spike... .40±.13
(b) stools per plant and kernels per spike.......... .16±.15
(c) stools per plant and weight per 1,000 kernels.... .28±.14

Of these correlations, only correlation (a) is significant statistically if three times the probable error is taken as indicating significance. But aside from statistical significance, none of these coefficients indicates marked correlation; and the conclusion, therefore, based on these data, is that these yield attributes approach a condition of independence in inheritance.

This conclusion is borne out by similar calculation on Grantham's data, the correlation between size of head and average number of tillers per plant being — .09 ± .15. However, the relation between number of kernels in 5 grams (seed weight) and number of tillers per plant is — .66 ± .085. That is to say, as the number of kernels in 5 grams decreases (seed increases in weight), the number of tillers per plant increases. This represents a significant and marked correlation. A low, positive correlation ($r = .23 \pm .14$) was obtained between number of kernels in 5 grams of seed and grams of seed in 25 spikes. As, therefore, the number of kernels in 5 grams increases (seed decrease in size) the head size increases. However, this coefficient is not significant statistically and probably has no value. It appears, therefore, that, in general, very little or no correlation exists between the yield attributes themselves, though the data are too meager and the number of strains used usually too small to give reliable results.

There is another way of getting at the genetic relationships between the yield attributes, though it is less satisfactory due to the confusing effects of environmental influences and the quantitative nature of the characters involved. Crosses can be made between strains in which the attributes are expressed to different degrees and the F_2 plants studied and classified with respect to these attributes. Thus, if AAbb be assumed to represent a strain of soybeans having a high proportion of three-seeded pods (AA) and a high percentage of abortive seeds (bb) and aaBB be assumed to represent a strain having a low proportion of three-seeded pods (aa) and a low percentage of abortive seeds (BB), then the parental as well as the recombination types (AABB, aabb) should be obtained in the F_2 provided there is independent inheritance or only a relatively small amount of correlated inheritance. However, on account of environmental effects and the complexity of inheritance of such quantitative characters, it will be difficult to recognize these recombination types and to separate them from the parental. Furthermore, if correlated inheritance is high, the desired combination would occur much less frequently than under independence and perhaps not at all.

Genetic relationships among the attributes themselves should be known. Knowing these, we can better understand and appreciate the

limitations, and determine what combinations, if any, may be easiest to secure by cross breeding. This implies that, first of all, the strains have been evaluated and that we know in what attributes each is superior or inferior, so that we know what strains to use as parents in crosses to get the desired combination in the hybrid.

CONCLUSION

In presenting these ideas, the thought has been to lay particular emphasis on the importance of breeding for yield as such. Present methods appear rather haphazard and unscientific, because selections and crosses are made without a knowledge of yield attributes and their genetic relationships to yield and to each other. Strains have not been sufficiently evaluated. A cross is made between two strains in the hope of getting something that is superior in yield to either parent. Chance plays a very large part in this—too large a part. It is probably too much to hope that the element of chance can be eliminated altogether in breeding for yield, but if we can by ever so little lessen the part that chance plays something has been accomplished.

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THE PRODUCTION OF AN ECONOMIC STRAIN OF WHITE BARBLESS BARLEY[1]

B. D. LEITH AND R. G. SHANDS[2]

Plant breeders and agronomists have long felt the need of a high-yielding barley without the objectionable saw-toothed beard. In 1915, at Wisconsin, several crosses were made between the Wisconsin Pedigree Oderbrucker and the hooded, the partly bearded, and the two-row barleys, in the hope that the objectionable beard could be eliminated or rendered less obnoxious by selection from the hybrid. In 1916, a new introduction of a black smooth barley was included in the crosses with the Pedigree Oderbrucker. The only selections of any economic importance have come from hybrids with the black smooth as a parent.

The purpose of this paper is to set forth briefly the methods used in producing the economically valuable strains of this barley, and to present data and observations that might be of interest to plant breeders and agronomists.

METHODS

The yield data from the Experiment Station at Madison are reported on 1/20-acre plats. These plats are planted approximately 1 by 8 rods, with a 3-foot alley between and a 16-foot alley at the ends to facilitate cutting with the grain binder. The alleys are sown to winter wheat in the spring to reduce the border effect. The plats are not replicated, but checks of a standard variety are planted alternately with them, giving each plat to be tested a check on each side of it. In the computation of yield all the checks are averaged. The two check plats and the variety to be tested are considered as a unit of area. The yield of the two checks is averaged and the percentage of this to the average yield of all the checks determined. As this percentage is computed from 2/3's of the unit area, it follows that the test plat bears this same relation to the whole field. In other words, the ratio between the plat to be tested to the whole field is the same as the checks on either side of it to the average of all the checks. This percentage, therefore, is used in determining the corrected yield of the plat to be tested.

[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Publication authorized by the Director December 8, 1930. Received for publication December 13, 1930.

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In the head rows are planted the heads from the first selection and all subsequent reselections. Selected heads from superior plants are returned to the head rows each year until the line appears to be homozygous.

The rod rows are used to study the relative economic qualities, such as length of straw and head, stiffness of straw, disease resistance, and yield, although, as has been noted above, the final yield determinations are made from the plat test which more nearly approximates field conditions. Large numbers of selections are tested in triplicate rod rows with checks every fourth or fifth row. The main purpose of the rod row is for reselection or elimination purposes. It appears to the writers that progress can best be made where a large number of lines are grown in the rod rows and drastic elimination practiced. If the selection shows some undesirable character in each of the triplicate rows, it is dropped or reselected. While the lines in the rod row may be apparently homozygous, there may still be considerable heterozygosity. After having been grown in the rod row a short time, a close inspection showed some barley selections to have varying degrees of smoothness in the awn and variation was also noted in the length of the lowest internode of the spike. Accordingly, several head selections were made for smoother awn and shorter internode and returned to the head row and the remainder discarded.

OBSERVATIONS AND DATA

The Wisconsin pedigree parent is a pure line selection from the Oderbrucker, the well known *Hordeum vulgare pallidum typica* Kcke-Harlan.[3] The smooth parent is *Hordeum vulgare nigrum leiorrynchum* Kcke-Harlan. This barley has short straw and a short head, black and glaucous. Many crosses have been made from these stocks. Several of the white smooth selections have been crossed back with the Pedigree Oderbrucker parent. Two selections of promising economic value, Pedigree 37 and Pedigree 38, have been put into the hands of farmers.

COLOR

The white color of the hybrids is not as clear as that of the Oderbrucker parent. A slight grayish color persists and a small amount of moisture discolors these barleys easily. A rather strong brownish discoloration is apt to appear at the base of the kernel from heavy dews. Several white hybrids were crossed back on to a Pedigree

[3]Harlan, H. V. The identification of varieties of barley. U.S.D.A. Bul. 622. 1918.

Oderbrucker to see if the color of this parent could be obtained, Some variation in the whiteness could be selected out in the progeny. but none of these were quite as clear white as the Oderbrucker parent. While the color is no detriment to its practical value, yet it is interesting to note that the white color is not a simple Mendelian character.

AWNS AND BARBS

So far as the authors have examined the awns of the smooth black parent, all have a few fine barbs near the tip, and none of the hybrids are entirely free from barbs. An examination of several progenies from hybrid selections crossed back with the Oderbrucker parent showed varying degrees of roughness on the awn. Some selections showed consistent variation, while others were as smooth as the smooth parent. The awns on those selected as superior economically are lighter and the kernel tends to hull at threshing more easily than the Oderbrucker.

INTERNODES

The basal internode beneath the spike is short on both parents, but many of the hybrids have a basal internode from ½ to ¾ inches in length. This did not seem to be a weak spot in the plant as was feared, but selection has been made away from it. General observation indicates that the short basal internode is associated with shorter heads. Often near the middle of the spike a double length internode appeared and two nodes occurred directly opposite each other on the rachis. As a result there were six spikelets together, three on each side. Both the Pedigree 37 and 38 average longer in head than the Oderbrucker due in part to a somewhat longer internode. However, counts made in 1928 show the Pedigree 38 to have about 5% more kernels than the Oderbrucker.

DATE OF MATURITY

While many of the hybrid selections matured in the same time as the Oderbrucker, the lines having the largest head and the most vigor have been about four days later in maturity. Earliness of maturity is usually considered an advantage in the hot days of summer. It appears, however, that Pedigree 38 and Pedigree 37 barleys can stand the heat of summer and make use of the few extra days growing period. This suggests an explanation of high yield, long heads, and plump seed.

STRIPE RESISTANCE

Barley stripe, *Helminthosporium gramineum* Rabh, causes considerable losses in the Middle West. In the Lake Michigan shore regions of Wisconsin, 10 to 15% infection is often found. This disease was also found in 1930 in all states in which field surveys were made, namely, Minnesota, Iowa, Nebraska, Illinois, Indiana, Michigan, and Ohio. The Oderbrucker barley shows considerable susceptibility to this disease, the Wisconsin Pedigree 6 being more susceptible than the Pedigree 5. In selecting the smooth hybrids, it was noted that some lines had no stripe and others were even more susceptible than the Pedigree Oderbrucker parent. In order to determine whether the difference in amount of disease in the selections was due to lack of opportunity to become infected or due to natural resistance, the smooth-awned selections were planted between the control rows of Pedigree 6. In this way the smooth-awned selections had a favorable opportunity to become infected.

When the seed from these rows was planted the following year, great variation in the amount of disease was noted. All of the X 39 (Ped. 5 x Leiorrynchum) selections proved to be highly resistant to stripe, one line of which has been entirely free for three years in succession. Selections from X57 (Leiorrnchum x Ped. 6) were intermediate in resistance. Selections from X69 (X57-10-4 x Ped. 5-1) varied from highly resistant to fairly susceptible. Selections from X105 (Ped. 6 x X39-3-9) were all susceptible, several lines even more so than the Pedigree Oderbrucker parent. The two Pedigrees 37 and 38 are both very resistant to stripe. The Pedigree 38 has remained very resistant in all of the tests in the state and in no case has there been over a trace. It proved to be equally resistant at Lafayette, Indiana, where other lines gave as high as 6% stripe.

YIELDS

Seven selections of the white barbless cross of 1916 were put into the yield test for the first time in 1925. Selections from later crosses are also shown in Table 1.

In 1926, the four higher yielding hybrid selections of the year previous were retained. From the earlier selections made in 1929 only two lines remain, Pedigree 37 and Pedigree 38. During the six years that the Pedigree 37 and Pedigree Oderbrucker were compared, the Pedigree 37 outyielded the Pedigree Oderbrucker by 7.6 bushels per acre. Comparing the yields of 1928, 1929, and 1930, the Pedigree 38 outyielded the Pedigree Oderbrucker by 6.5 bushels per acre and the Pedigree 37 by 4.5 bushels per acre.

A brief statement of the relationship of the selections mentioned in Table 1 may be of interest. X39 is a cross made in 1916 between the Pedigree 5 Oderbrucker as the male and *leiorrynchum* as the female parent. Both Pedigrees 37 and 38 have their origin from this cross. The numbers following the dash indicate the selection numbers.

TABLE 1.—*Yields of selections of White Barbless and Pedigree Oderbrucker barley.*

Selection	Yield in bushels per acre					
	1925	1926	1927	1928	1929	1930
Oderbrucker, Wis. Ped. 6	58.5	41.5	37.7*	49.0	29.5	41.6
White barbless selections:						
x39-5 (Ped. 37)	69.0	60.3	47.8	41.7†	43.7	40.7
x39-9	65.4	52.0	53.1	—	—	—
x39-2	60.4	55.7	53.8	40.3	—	—
x39-8	58.0	—	—	—	—	—
x39-11	52.5	42.9	—	—	—	—
x39-13	49.9	—	—	—	—	—
x39-6	48.1	—	—	—	—	—
x39-9-3 (Ped. 38)	—	—	—	46.4‡	47.7	45.5
x39-9-3-4	—	—	—	67.2	44.1	46.7
x60-2-1	—	—	—	53.1	37.3	44.3
x60-2-3	—	—	—	52.4	37.0	45.2
x57-27-5-5	—	—	—	49.2	33.5	38.7
x57-12-4-13	—	—	—	42.9	47.4	59.1
x105-2-4-1	—	—	—	—	30.1	36.3
x105-2-4-2	—	—	—	—	29.4	39.3

*Beginning with 1927, the Pedigree 5-1 Oderbrucker was used as a check.
†A field of 11.5 acres yielded 50 bushels per acre.
‡A field of 1¼ acres yielded 53 bushels per acre.

The X57 cross was made in 1920 with *leiorrynchum* as the female and Pedigree 6 Oderbrucker as the male parent.

X60 is a cross between *leiorrynchum* as the female and a Pedigree Oderbrucker (number not given) as the male parent. The two selections from this cross were somewhat lighter in color than the previous crosses.

The X105 cross was made in 1924 between Pedigree 6 and X39-3-9. This cross made such a splendid appearance in the rod row in 1927 that it was increased in 1928 and put into the 1/20-acre plats in 1929. The plat tests however have been rather disappointing.

REGIONAL TESTS

The Experiment Station test, though in comparison with other lines and under controlled conditions, is after all only a local test. What a new hybrid selection will do under the varying conditions of soil and climate in the state must also be determined. As soon as possible, a small increase was made of the most promising selection

and in 1927 half-bushel lots were sent out to county agents to give a farm trial in five different regions of the state; two near Lake Michigan in the eastern part of the state, one in the north central, and two in the western part. The results were so encouraging that more of this selection, Pedigree 37, was sent out in 1928. In the meantime another selection, Pedigree 38, was showing some superiority over the Pedigree 37 at the Station and it was sent out in 1929. Farm tests to date indicate that Pedigree 38 is somewhat to be preferred over Pedigree 37. Of 67 farmers reporting yields of Pedigree 38 in 1930, 19, or 28%, report yields of 60 bushels per acre or above; 45, or 67%, yields of 50 bushels or above. While 1930 was a good year for small grains, several report much lodging due to storm damage.

SUMMARY

In 1916, hybridization work was started at the Wisconsin Experiment Station to produce a pure line selection of white barbless barley from a cross between a black smooth type and the Pedigree Oderbrucker parent. While smoothness of the selections vary, lines can be isolated as smooth as the smooth parent.

A long basal internode appears in the best strain, Pedigree 38. Progress in selecting for long head with short basal internode is difficult because of the apparent linkage of long internode and long head.

The highest yielding strains are about four days later in maturity than the Oderbrucker parent, and the heads are longer and the kernels plumper.

Variations in stripe resistance from highly resistant lines to those more susceptible than the susceptible parent have been isolated. Pedigrees 37 and 38 are very resistant.

Pedigree 38 has proved a high yielder in the hands of farmers. In the Station test plats over a three-year period, 1928–30, it has exceeded the Oderbrucker in yield by 17%.

NATURAL CROSSING IN BARLEY AT FORT COLLINS, COLORADO[1]

D. W. ROBERTSON AND G. W. DEMING[2]

In studying genetics in barley, it has been noticed that intermediate forms have often been found in parental material. Some varieties showed more of these off types than others, and on further testing they were found to be F_1 hybrids which segregated the following year. In order to determine the amount of natural crossing, a study with this point in view was started in 1927.

Hayes and Garber[3] cite Fruwirth, Rimpau, and Harlan as having observed very little natural crossing in barley. They conclude that, "Barley probably, therefore, crosses much less frequently than does wheat."

Stevenson[4] grew white-hulled varieties between black-hulled varieties at the Minnesota Station in 1924, 1925, and 1926. He concluded that natural crossing varies with the variety. No hybrids were found in Hanna or Oderbrucker, but small amounts of natural crossing, *viz.*, 0.04% for 1924, 0.12% for 1925, and 0.15% for 1926, were found in Consol, while 1 natural cross out of a total of over 10,000 plants was found between Manchuria, Minn. No. 184, and one of the black types. No natural crossing was observed between Manchuria, Minn. No. 184, an awned variety, and Nepal, a hooded variety. He also concluded that seasonal differences did not have as great an effect as varietal differences.

MATERIAL AND METHODS

The following varieties were used in the study carried out at Fort Collins:

Colsess . . . . A white-hulled, hooded, 6-rowed variety

Trebi . . . . A white-hulled, 6-rowed, awned variety

Hordeum deficiens nudideficiens. A white-hulless, awned, 2-rowed variety

[1]Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication December 16, 1930.

[2]Associate Agronomist and Assistant Agronomist, respectively.

[3]HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Company. Ed. 2. 1927.

[4]STEVENSON, F. J. Natural crossing in barley. Jour. Amer. Soc. Agron., 20: 1193–1196. 1928.

H. distichon nigrinudum.......A black-hulless, awned, 2-rowed variety
Blackhull..................(C. I. 878) A black-hulled, awned, 2-rowed variety
Black six row...............A black-hulled, awned, 6-rowed variety

The above varieties were sown in 18-foot rows. The rows were 6 inches apart. The planting plan for the different varieties is given in Table 1.

TABLE 1.—*Planting plan of varieties planted to study the amount of natural crossing in barley under Colorado (Fort Collins) conditions.*

Row No.	Year grown		
	1927	1928	1929
1	Blackhull	Trebi	Trebi
2	*H. def. nudideficiens*	*H. def. nudideficiens*	Blackhull
3	Blackhull	Blackhull	Trebi
4	Colsess	Colsess	Black six-row
5	Black six-row	Blackhull	Trebi
6	Trebi	Trebi	*H. dis. nigrinudum*
7	*H. dis. nigrinudum*	Blackhull	Trebi
8	*H. def. nudideficiens*	*H. dis. nigrinudum*	Colsess
9	Black six-row	*H. def. nudideficiens*	Blackhull
10	Colsess	*H. dis. nigrinudum*	Colsess
11	Black six-row	Colsess	Black six-row
12	Trebi	*H. dis. nigrinudum*	Colsess
13	Black six-row	Trebi	*H. dis. nigrinudum*
14	Colsess	*H. dis. nigrinudum*	Colsess
15	*H. dis. nigrinudum*	Black six-row	*H. def. nudideficiens*
16	Trebi	*H. def. nudideficiens*	Blackhull
17	*H. dis. nigrinudum*	Black six-row	*H. def. nudideficiens*
18	———	Colsess	Black six-row
19	———	Black six-row	*H. def. nudideficiens*
20	———	Trebi	*H. dis, nigrinudum*
21	———	Black six-row	*H. def. nudideficiens*
22	———	Trebi	Colsess

All of the varieties grown head about the same date with the exception of *H. def. nudideficiens* which heads about 6 days earlier under Colorado conditions. Under nursery conditions this variety crosses freely and has to be very closely rogued to keep the strain pure. The plants often stand with the florets wide open for several days after fully heading. No examination has been made to determine if the pollen is sterile or to ascertain any other cause for this condition.

HARVESTING METHODS

Each row was harvested separately. The plants were pulled up and thrashed singly. A single head row (3 feet long) was planted from the seed of each plant. The rows were harvested in the fall and

counts made of hybrids and normal plants. Table 2 gives the characters of numerous hybrid F_1 plants found in *H. def. nudideficiens* in 1930.

TABLE 2.—*Head characters of F_1 plants grown from an 18-foot row of H. def. nudideficiens.*

Number of plants	Head characters
58	Awned—Black—Intermediate—Covered
11	Awned—Black—2-rowed—Naked
35	Awned—Black—2-rowed—Covered
61	Awned—White—Intermediate—Covered
1	Awned—White—Intermediate—Covered, short awn
4	Awned—White—Intermediate—Naked
6	Awned—White—2-rowed—Naked, different from parent
10	Hooded—Black—Intermediate—Covered
2	Hooded—Black—Intermediate—Naked
1	Hooded—Black—2-rowed—Naked
2	Hooded—Black—2-rowed—Covered
Parent	Awned—White—2-rowed—Naked

Several plants which, without doubt, were mechanical mixtures were discovered. Several such awned plants were found in the hooded varieties grown. A few F_2 rows were also found in the head row material. Such rows were easily distinguished from rows with F_1 plants present by their close approach to Mendelian ratios when the normal and off-type plants were counted. In Black six-row one segregating row was found in 1928, eight in 1929, and one in 1930. In Colsess two rows segregating for hoods and awns were found in 1929 and one in 1930. In *H. def. nudideficiens* two rows segregating for head type were found in 1929, and in *H. dis. nigrinudum* two rows segregating for color and rows were found in 1928. These were not used in the counts.

The hybrid plants are easily identified in all of the varieties. To identify them further a random sample of F_1 plants was grown in 1930, all of which segregated for rows or color in the F_2. Intermediate plants in two- or six-rowed varieties, hooded plants in awned varieties, black plants in white varieties, covered plants in naked varieties, or combinations of these characters were considered as hybrids. In all of the varieties tested, the possible parentage of the hybrids was easily accounted for. In *nudideficiens*, many off types were found whose origin could only be accounted for by crossing with nearby varieties grown for genetic studies.

RESULTS

The total number of plants breeding true and the number of F_1 plants obtained in 1927, 1928, and 1929 are given in Table 3.

TABLE 3.—*Total number of plants breeding true and F_1 plants found in varieties grown adjacent to each other in 1927, 1928, and 1929.*

Variety	1927			1928			1929		
	True breeding	Hybrid	%	True breeding	Hybrid	%	True breeding	Hybrid	%
H. def. nudideficiens	5,718	193	3.265	5,491	1,434	20.708	14,142	848	5.657
Black six-row	11,293	17	0.150	24,595	16	0.065	21,184	15	0.071
H. dis. nigrinudum	5,012	0	0.000	23,536	13	0.055	15,968	22	0.138
Colsess	18,376	6	0.033	39,510	6	0.015	50,669	6	0.012
Trebi	16,241	0	0.000	38,447	7	0.018	35,295	2	0.006
Blackhull	7,183	0	0.000	18,743	1	0.005	11,368	0	0.000

Only one hybrid was obtained in Blackhull. This plant was tested in 1930 and found to segregate for color and rows. Trebi showed a small amount of natural crossing, about 1 plant in every 10,000. In Colsess, about 2 plants were found in every 10,000. This possibly may be a little low since Colsess x Trebi crosses could not with certainty be identified in F_1 material. In *H. dis. nigrinudum* and Black six-row, about 1 hybrid was found in every 1,000 plants. The Black six-row hybrid count may be low, since Black six-row x Trebi crosses are hard to distinguish from true Black six-row plants. The hybrid number in *H. def. nudideficiens* was high, varying from 3.265 to 20.708%. This variety is exceedingly hard to keep pure, but fortunately is of little or no commercial value. Of the commercial varieties grown, Trebi and Colsess show a low natural crossing percentage, but this is of sufficient magnitude to make it necessary to rogue these varieties systematically to keep them pure.

The effect of season on the percentage of natural crossing is shown in Table 4.

TABLE 4.—*The effect of season on natural crossing in barley at Fort Collins, Colorado.*

Variety	1927		1928		1929	
	Actual % natural crossing	% calculated	Actual % natural crossing	% calculated	Actual % natural crossing	% calculated
H. def. nudideficiens	3.265	100*	20.708	634	5.657	173
Black six-row	0.150	231	0.065	100	0.071	109
H. dis. nigrinudum	0.000	—	0.055	100	0.138	251
Colsess	0.033	275	0.015	125	0.012	100
Trebi	0.000	—	0.018	300	0.006	100
Blackhull	0.000	—	0.005	100	0.000	—

*The percentage increase is determined by assuming the lowest percentage of each variety as 100 and calculating the other percentages from this.

There seems to be a greater difference between varieties than between seasons. While the seasonal effect is noticeable, it is not uniform in its effect on the different varieties. There seems to be a greater effect on the variety with a high percentage of natural crossing than on the varieties with a low percentage.

DISCUSSION

The above data agree with Stevenson who found natural crossing in barley to vary with the varieties tested. He found a low percentage of natural crossing in white six-rowed barleys. The seasonal effect seems under both Minnesota and Colorado conditions (high and low humidity) to have less effect than the varietal differences.

SUMMARY

Natural crossing occurs in barley under Colorado climatic conditions.

The commercial varieties of barley showed a low number of natural crosses. In Trebi, approximately 1 hybrid plant was found in every 10,000; in Colsess, approximately 2 hybrid plants in every 10,000; and in Blackhull, only 1 hybrid plant in some 37,295 plants studied.

The number of natural crosses varied with the variety. *H. def. nudideficiens* showed 3.265% in 1927, 20.708% in 1928, and 5.65% in 1929. The other varieties tested showed less than 0.15%.

The variation between varieties was greater than the variation between seasons.

NATIVE VEGETATION IN THE PRE-HISTORIC LAKE BONNEVILLE BASIN[1]

GEORGE O. BURR[2]

This paper is a presentation of some of the work of Dr. J. Arthur Harris and his associates in the western deserts. It should be emphasized that, although there were many men associated with Dr. Harris in this work, he alone was responsible for its inception and continued development.

It was early recognized by Dr. Harris that the greatest task of biologists was the placing of biology alongside of physics and chemistry in the ranks of the exact sciences. Phytogeography is admittedly one of the least quantitative of the biological sciences, yet the exact methods of physics and chemistry can be successfully employed for its advancement. It was recognized, however, that the plant in its natural habitat is so variable that the physico-chemical measurements could not be used to their greatest advantage without careful biometric treatment. Through the proper application of Pearsonian statistical methods to the data collected, the degree of variation of plants and the correlation of these variations to soil and climatic conditions can be quantitatively expressed.

Those measurements which have proved to be most readily made in large numbers under field conditions are the osmotic concentration and ionized salt concentration of the leaf sap. These measurements were often supplemented by more or less complete soil analyses and at times by the measurement of the concentration of specific ions in the leaf sap, as, for example, the H ion, Cl ion, and SO_4 ion. But by far the greatest number of determinations have included only osmotic concentration and electrolyte content of the leaf sap. Fortunately, these measurements can be made quickly and accurately by the finding of the depression of the freezing point and the electrical conductivity. For each degree that the sap freezes below the freezing point of pure water, there is an osmotic concentration equal to about 12.06 atmospheres osmotic pressure across a completely semipermeable membrane. The electrical conductivity cannot be so readily restated in terms of total electrolyte concentration so this measurement is recorded as specific conductivity.

[1]Contribution from the Department of Botany, University of Minnesota, Minneapolis, Minn. Also presented at the annual meeting of the Society held in Washington, D. C., November 21, 1930. Received for publication December 18, 1930.

[2]Associate Professor of Botany.

The scope of this paper has been limited to studies made on native vegetation in the Lake Bonneville Basin of Utah. Time will not permit us more than the mention of the extensive work of a similar nature in the Arizona deserts, the Coastal deserts and Montane rain forests of Jamaica, the arid portions and rain forests of Oahu, Hawaii, the saline swamps and sub-tropical jungles of southern Florida, and numerous other localities, which were extensively studied by Dr. Harris.

The great, obscurely triangular desert area of the United States has a base of 800 miles along the Mexican border, with its apex in north-central Oregon.[3] It includes the whole or portions of the states of Texas, New Mexico, Colorado, Utah, Idaho, Arizona, Nevada, California, and Oregon. Its total area is about half a million square miles. The Great Basin lies on the northwestern side of this desert country and is the largest area in North America with interior drainage. But North America is not characterized by interior drainage and all other continents have larger basins than ours. The Great Basin is also rudely triangular in form. The extreme length north and south is about 880 miles and its extreme breadth east and west is 572 miles. The total area is approximately 210,000 square miles or nearly half of the desert area. It is not, as the name might suggest, a single depression gathering its waters at a common center, but a broad area of varied surface naturally divided into a large number of independent drainage districts.

With a prevailing air drift from west to east and the Sierras presenting an unbroken barrier 10,000 feet high, this region is very arid. The lowlands have an annual rainfall of possibly 7 inches and an ability to evaporate 60 to 80 inches of water per year from free water surfaces. The average relative humidity is probably 20 to 25% below that of the states just east of the Mississippi River. The story of the climate is eloquently told by the hydrography and the vegetation.

The Great Basin includes from 60 to 100 subsidiary closed basins, each draining to a lake or playa. In the last geologic epoch a more humid climate converted many of these playas into lakes and caused many of the lakes to combine into larger bodies. The largest of these lakes was Lake Lahontin on the west, fed by the snows of the Sierras, and Lake Bonneville on the East, fed by the Wasatch and Uinta Mountains. The Lake Bonneville Basin is about 54,000 square miles

[3]The notes concerning geology and climate have been taken from G. K. Gilbert's "Lake Bonneville", Dept. Interior, U. S. Geological Survey, Washington, D. C., Vol. 1, 1890.

in area, and the lowlands have an altitude of 4,200 to 5,500 feet above sea level. It extends from southern Idaho 300 miles south into Utah and from Salt Lake City on the east about 125 miles westward to the Nevada plateau. This is not one great unbroken plain, but is interrupted by short mountain ranges running north and south. The chief large open areas are the Great Salt Lake Desert, the Sevier Desert, and the Escalante Desert. The high mountains to the east give rise to perennial streams which are now used for irrigation. Possibly no greater variety of soil and moisture conditions can be found elsewhere in so small an area.

Much of the work has been done within a 75-mile radius from Nephi, Utah, the location of the central laboratory. This country presents ideal opportunities for such research. Here the lofty mountains rising abruptly from the desert afford such soil moisture and low temperature as are provided by the shores of a cold mountain lake. In sharp contrast to these conditions, which foster the growth of a rich subalpine vegetation, are the vast arid and sparsely vegetated plains and nearly sterile mountains of the great deserts. In places there are volcanic craters and broad lava flows. On these, plants must carry on the struggle for existence against drought on a rock terrain which affords but scanty soil in the crevices.

Lake Bonneville had a profound influence on the physiographic features of the region. Its waves cut great sea cliffs along the sides of the mountains. Sand bars were deposited close to shore and the finer silt was carried far into the lake. Since the disappearance of the waters in the present era of aridity, these sands have been blown into great shifting dunes. In places they afford a precarious foothold for plants. Sometimes favorable conditions permit the establishment of sparse vegetation over the dunes, but sooner or later the dunes move forward to overwhelm whatever is in their paths. Large cedars are often submerged.[4]

The finer clay and silt sank into the deeper waters. Since the dessication of the lake bed, these impalpable fine clays have become impregnated with salts from the waters of the lake and from the waters which have since flowed into them. These lowest silt-clay deposits are at the bottom of small closed basins without permanent creek or lake. Over much of the area of these almost sterile playas or alkali flats water is found at but a few inches or a few feet below the surface. During storms a few inches of water will cover the entire surface. But this presence of water cannot assure the growth of any but two or three species of plants, especially adapted to such con-

[4]Much of the description of habitats is due to Dr. Harris.

ditions, for the water often contains as much salt as, and sometimes much more than, sea water. This is gradually brought to the surface by evaporation and the crust thus formed glistens like snow in the sunlight.

The results of these investigations have confirmed the pioneer findings of Kearney, Briggs, Shantz, McLane, and Piemeisel that it is possible from an inspection of the vegetation to draw fairly definite conclusions concerning the physical and chemical properties of the soil in this region. At the time of the earlier work (1911–13), however, methods for the precise measurement of the physico-chemical properties of plant saps were not available. By the technics which were applied by Dr. Harris, it is readily demonstrated that there is a close parallelism between the physico-chemical properties of the tissue fluids of the native species, on the one hand, and the characteristics of the soil and capacity of the land for crop production, on the other.

Eight major divisions of the vegetation have been recognized, *viz.*, the higher mountain areas, the sagebrush association, the sand-hill mixed association, the Kochia association, the shadscale association, the greasewood-shadscale association, the grass-flat communities, and the salt-flat communities. These divisions are listed almost in order of lowering altitude and increasing salinity. The electrolyte content of the leaf sap increases progressively from the mountain to the salt flats. It was shown by Harris and co-workers in 1921 that ligneous and herbaceous plants differed markedly in their sap properties. Trees and shrubs have a higher osmotic concentration and a lower electrolyte content than do the herbs. This is so marked that the ratio of conductivity over freezing point depression $\left(\frac{K}{\Delta}\right)$ is almost twice as high in the herbaceous plants. For this reason the two types must be kept separate in the discussion of averages. In the ligneous plants, the average chloride content increased from 0.68 gram per liter of sap in the Stansbury mountains to 26.45 gram per liter of sap in the salt-flat communities. There is a general tendency also for the osmotic concentration to increase as the lower and more saline regions are reached.

A study which yielded some of the most interesting results was carried out during the summers of 1926, 1927, and 1928. This work has been assembled in the doctorate thesis of Vernon A. Young,[5] and is as yet unpublished. Only those areas that lie at the level of, or below the base of, the old Bonneville shore-line have been given

[5]Young, V. A. Chemical factors of the soil which influence the distribution of desert vegetation. University of Minnesota, 1929.

careful consideration. A detailed examination was made of limited areas which supported pure greasewood (*Sarcobatus vermiculatus*), pure sagebrush (*Artemisia tridentata*), and mixed greasewood and sagebrush.

It was suspected that these soils were heterogeneous and that this heterogeneity determined in some measure the location of the individual plants. But a surprising degree of heterogeneity was found and the limiting factor for growth of sagebrush became evident.

Soil tubes were driven right through the roots at the base of the plants in sampling. Samples were taken at 1-, 2-, 3-, and 4-foot levels. The soil was extracted with 5 parts of water, and determinations of SO_4, Cl, CO_3, HCO_3, H ion concentration, and specific conductivity were made. It was found that the salts in the first 2 feet of soil were distinctly higher around the greasewood than around the sagebrush. But the most remarkable difference appeared in the alkalinity. For example, on the bench west of Nephi, out of 18 pairs of plants picked because they were close together, there was no exception to the rule that the soil about the greasewood was more alkaline, as measured by pH, than the soil about the sage. This difference was most marked in the first foot, persisted through the second foot, and was lost in the third and fourth feet. But the sage spreads its roots close to the surface and is limited largely by the condition of the surface soil. The plants were never more than a few yards apart and sometimes within 3 or 4 feet of each other, yet the soil about the greasewood was usually 10 times as alkaline, i. e., there was a whole pH difference.

The average H ion concentration for the soil of a healthy pure sage habitat on Levan Ridge was pH 7.36, while for a healthy pure greasewood habitat in Tintic valley it was pH 9.21. The greasewood habitat could not be invaded by sage, which cannot thrive in a soil whose surface foot is much more alkaline than pH 7.5. There is a factor of nearly 100 separating these two plants. Yet because of the spotted condition (heterogeneity) of some of the desert soils, these plants can grow within 3 feet of each other.

Throughout this work, the problem of drought resistance has been kept in mind. The data have been searched for possible differences between plants known to be highly resistant to drought and plants which are not. It has been widely recognized that drought resistance is determined by three major factors, *viz.*, intake of water by the plant, loss of water by the plant, and certain internal structural and chemical conditions. When the water supply is plentiful, all plants thrive; but when transpiration exceeds water intake, the plant is in a

negative water balance and must quickly readjust itself. It is the problem of the desert plant to maintain a positive water balance from year to year and still expose the maximum possible surface for the absorption of carbon dioxide from the air. It is only with the internal factor that this discussion is concerned.

Drought resistant plants may be conveniently divided into the succulents represented by the cacti and those xerophytes which are not of the succulent type. The succulents are common in North America, but they do not grow well in the hottest and driest parts of the deserts, nor are they common in the Sahara or the Deserts of Gobi. They have developed such a shape that they expose a very small surface in proportion to their volume. They resemble epiphytes in their low osmotic concentration, and are adapted to live in deserts of moderate rainfall.

But all xerophytes are not thus compelled to reduce transpiration. Other means of reaching a satisfactory water balance have been used. These include extensive root systems, ability to wilt for long periods and then recover, ability to lose foliage and enter a resting stage, etc.

One other peculiarity of the xerophytes is their relatively high osmotic concentration. This was first noticed by Zalenski in 1904 and extensive measurements were made in 1911 by Fitting, using plasmolytic methods. Using the more rapid and exact method of freezing point depression, Harris and co-workers have shown this relation to hold for thousands of determinations made in widely varied habitats. Hannig, Iljin, Maximov, and others have also confirmed these findings. This increased osmotic concentration seems to be an inherent peculiarity of xerophytes. When xerophytes are growing along side of mesophytes under identical moisture conditions, the xerophytes will develop the more concentrated sap.

The exact mechanism by which a higher osmotic concentration might aid plants to withstand drought is not clear. Fitting stated the two obvious conclusions that a higher osmotic concentration of the sap aided the uptake of water from the soil and cut down transpiration rate in the leaves. Neither of these stands without severe criticism. Livingston has strongly opposed both ideas. In the first place, the work of Briggs and Shantz has indicated that all plants possess approximately the same power to remove water from the soil. Secondly, it can be shown that saps of high osmotic concentration evaporate from an open dish at approximately the same rate as more dilute saps. However, Keller has recently shown that if *Salicornia herbacae* is grown in cultures of increasing salinity, the intensity of

transpiration decreases with increasing concentration. Maximov[6] thinks that high osmotic concentration may aid in preventing visible wilting with large losses of moisture.

Whatever the mechanism of the effect, the results fully justify the conclusions that the capacity of the plant to resist drought is in some degree dependent on the concentration of its tissue fluids. It is a property of all plants that they tend to maintain an osmotic concentration somewhat higher than that of the solution in which they grow. This explains the high concentration of electrolytes in the sap of the halophytes characteristic of salt flats. It is evident that this concentration is not for the purpose of drought resistance in the ordinary sense, since an excess of saline water is always present. The higher concentration in the plant is necessary for maintaining a positive osmotic gradient from the soil to the roots and this gradient probably persists from the roots to the leaves. The halophytes of the Lake Bonneville Basin are peculiar, not in their drought resistance, but in their tolerance to high salt concentration. Saline solutions have been described as a "physiologically dry" environment and in this sense halophytes are comparable to xerophytes.

The vegetation of the Lake Bonneville Basin is striking in its sharp contrasts and sudden transitions from the true xerophyte sage to the alkali-loving greasewood and then to the salt-tolerant halophytes. It is hoped that the many thousands of unpublished determinations and field notes of Harris and co-workers can, in the near future, be published so that they will be available to other workers. We have no hope at present of applying to this material the adequate biometric treatment which Dr. Harris would have given.

NOTE

IMPROVEMENT FOR HAND CLOVER HULLER

A hand clover huller, a description of which appeared in this JOURNAL, Volume 22, pages 476–477, has been improved so as to increase considerably its hulling efficiency. Two changes have been made and are described as follows:

1. A narrow strip of circular galvanized iron has been fastened on either end of the wooden drum in such a manner as to extend about three-quarters of an inch beyond the outer circumference of the drum, thus providing a flange. This flange serves to prevent the threshed clover seed from falling between the end of the drum and the frame of the machine and thereby obviates the danger of mixing different lots of seed.

[6]MAXIMOV, N. A. The Plant in Relation to Water. London: 1929.

2. (a) A galvanized wire screen, 20 mesh to the inch, has been substituted for the tapestry on the surface of the revolving drum. This provides a harder, more enduring, and better rubbing surface than does the tapestry. (b) A galvanized wire screen, 14 mesh to the inch, has also been substituted for the tapestry referred to as the apron. With a mesh of this size the clover seeds pass through as fast as they are hulled.

Accordingly, instead of using tapestry as the rubbing surfaces, screen wire is employed. With these changes the hulls are quickly and completely removed with a minimum of damage to the clover seeds.

3. A piece of galvanized iron has been slipped into a narrow groove, in a slanting position, behind the cylinder. This prevents the cylinder from carrying or throwing the clover chaff and straw back of the drum unthreshed and down into the box below where the threshed material falls.

These changes have been suggested by F. N. Jones, the original builder of the huller, and Claude Greenham who has been operating the huller during the past year or more.—G. H. CUTLER, *Department of Agronomy, Purdue University, Lafayette, Indiana.*

BOOK REVIEWS

PRINCIPLES OF SOIL TECHNOLOGY

By Paul Emerson. New York: The Macmillan Co. XV + 402 pages, illus. 1930. $3.25.

The subject of soil technology is treated under four main headings, *viz.*, (1) soils in general, their formation and classification; (2) the physical properties and functions of soils; (3) the chemical properties and functions of soils; and (4) soil biology.

The discussion of soil formation is prefaced with a brief consideration of the theories of the origin of the earth and of the geological history of the earth. Reference can be found to most any subject having to do even remotely with soils. While this extensiveness may be impressive to the student, it necessitates passing over many of the more important aspects of soils with only brief mention. The relation of soils to plant growth is treated in a brief chapter at the end of each of the last three parts of the book.

One of the most valuable characteristics of the book is the large number of references to recent literature, which are given in footnotes. The discussions of this work however, are, frequently fragmentary and obscure. Many inaccurate statements occur. For example, the *Internationale Mitteilungen für Bodenkunde* is cited as the chief current German publication on soil science in spite of the fact that it was discontinued about five years before this text was published.

Another valuable feature of the book is the 45-page appendix which contains a useful series of charts showing climatic data, vegetation, and soil maps; tables giving the chemical and mechanical an-

alyses of typical soils; and the extensive glossary of terms which has been taken largely from the report of the Committee on Terminology of the American Soil Survey Association. The book is of unquestionable value as a reference book. As a text for the average college course it leaves much to be desired. (R. B.)

VEGETABLE CROPS

By H. C. Thompson. New York: McGraw-Hill Book Co. IX + 560 pages, illus. Ed. 2. 1931. $5.

This second edition has been revised and rewritten, and brought entirely up-to-date. It differs from the first volume chiefly in the boiling down of the references to experiments which are discussed throughout the volume. In the first edition lengthy quotations were used, while in this edition the author has expressed in a much more concise form in his own words the essential points in the experiments under discussion. This has greatly reduced the space required for each reference.

In spite of this reduction, so much new material, covering all the latest work in vegetable crops, has been added, that this second edition contains 560 pages, as compared with only 478 pages in the first edition.

The subject of vegetable growing is discussed primarily from the standpoint of plant physiology, as was the case in the previous edition. The subject is presented in excellent style from the standpoint of scientific principles, and their practical application. In this way the book is most admirably adapted for student use, as well as for practical gardeners. (C. B. S.)

AGRONOMIC AFFAIRS

SUMMER MEETING OF SOUTHERN AGRONOMISTS

The 1931 summer field meeting for workers in agronomy in the southern states will be held in North Carolina August 25 to 27, with details of the itinerary to be announced later. C. B. Williams, head of the Department of Agronomy, North Carolina State College, State College Station, Raleigh, North Carolina, is in charge of the meeting, and announces that the field trip will be arranged so as to give visiting agronomists as comprehensive a conception as possible of the agronomy work under way in North Carolina.

A SUGGESTED REVISION OF THE NAME OF THE SOCIETY

The following suggestion as to a change in the name of the Society has been offered by Morris Halperin of the California College of Agriculture at Davis and has been referred to the special committee that is making a study of the reorganization of the Society.

"Consultation of standard dictionaries for a definition of 'society' makes manifest the fact that this word, except for its metaphorical-

technical use in an expression such as 'plant society,' invariably denotes an association of two or more persons. In other words, the *quality* denoted by the term 'society' is always human, and the *quantity* is at least two.

"From this point of view, a person reading the expression 'society of' in the title of an organization naturally expects it to be followed by a noun which denotes persons and is plural in number. In a title such as 'The American Society of Agronomy,' the word 'agronomy,' first, denotes an abstract subject rather than a concrete person, and, second, is singular rather than plural. Inasmuch, however, as our society is, as a matter of fact, a society of agronomists, and inasmuch as the word 'agronomists' not only denotes concrete persons but is also plural in number, it would seem to be both logical and grammatical to use 'agronomists' as the word to denote, in the title of our society, the composition of it.

"It is therefore suggested that the present name be replaced by 'The American Society of Agronomists.' "

THE PENNSYLVANIA SOIL FERTILITY CONFERENCE

Invitations and programs for the Soil fertility Conference to be held at the Pennsylvania State College, June 24, 25, and 26, have been mailed to members of the American Society of Agronomy.

The program is technical and is based on detailed studies of the old plats. Any one interested, who failed to receive a program, should address, F. D. Gardner, Department of Agronomy, State College, Pa.

SUMMER MEETING OF CORN BELT SECTION

Immediately preceding the Pennsylvania Soil Fertility Conference, the Corn Belt Section of the Society will hold its summer meeting at Purdue University on June 22 and 23. The program will consist largely of an inspection of the soils and crops and allied experimental work at Purdue. A special address on "Trends in Corn Belt Agricultulture" will be a feature at the Section Dinner on Monday evening. The program is so arranged that those interested chiefly in soils and intending to drive through to the Soil Fertility Conference at Penn State can leave Monday evening.

NEWS ITEMS

The Fifteenth International Congress of Agriculture is to be held in Prague, Czechoslovakia, next month, with Sections on Agrarian Politics and Rural Economy, Agricultural Teaching and Propaganda, Agricultural Cooperation, Plant Production, Animal Production, Agricultural Industries, and Womand in the Country.

Dr. Felix Löhnis, for many years a member of the Society, died in Leipzig on December 8, 1930. Dr. Löhnis, well known for his researches in agricultural bacteriology, entered the services of the U. S. Dept. of Agriculture in 1914 as Soil Bacteriologist, and in 1923 was put in charge of the Office of Soil Bacteriology Investigations of the Bureau of Plant Industry. He resigned in 1925 to return to his alma mater, the University of Leipzig.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 JUNE, 1931 No. 6

MICROBIOLOGICAL CHANGES OCCURRING IN A SOIL UNDER PASTURE AND BARE CONDITIONS[1]

HERBERT W. REUSZER[2]

A study of the microbiological activities of pasture soils affords an interesting subject, both from a practical and from a scientific viewpoint. Huxley (8)[3] has recently called attention to the importance of grasslands in the past and future of civilization and the influence of soil conditions thereon. The economic position of pastures in the United States has been summarized by Piper and associates (18). They point out that in 1919, 1,055,000,000 acres, or approximately 55% of the total land area of the United States was used exclusively for grazing.

From the more strictly scientific viewpoint, grassland soils offer an opportunity for the study of soils under conditions approaching those found in nature where an equilibrium has been reached between the soil, the soil organisms, and higher plant life. This is particularly true of arid or semi-arid grassland soils where the vegetation is usually of a climax or sub-climax type. In humid regions, however, the equilibrium may not be so well established, due to the disturbance of the native vegetation by cultivation. There is some evidence (23), however, that here too the vegetation of permanent pastures tends to approach a more or less stable condition, particularly on old or virgin pastures, and in some cases even on compara-

[1]Part of a thesis submitted to the faculty of Rutgers University in partial fulfillment of the requirements for the degree of master of science, May, 1930. Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Soil Chemistry and Bacteriology. Received for publication December 19, 1930.

[2]The author wishes to express his indebtedness to Dr. S. A. Waksman for advice and encouragement offered during the course of this investigation.

[3]Reference by number is to "Literature Cited," p. 427.

tively young pastures. A study of pasture soils then should be of interest to the student of soil origins and to the soil microbiologist who is interested in the relations between higher plants and soil organisms or the effect of micro-organisms in soil profile development.

HISTORICAL

The effects which growing plants may have upon micro-organisms in the same soil have been the subject of considerable investigation. Starkey (24) has recently reviewed the literature on this subject and no attempt will be made to review it in detail here. It will be of interest, however, to call attention to certain investigations dealing more specifically with the effects of a sod grass cover on certain microbiological phenomena of a soil.

Although the nitrate nitrogen content of soils growing crops has been found (13, 14) to approach or even exceed that of similar fallow soils, the nitrate content of grassland soils has uniformly been noted as being very low. Arranged in the order of descending values, Ladd (11) found the nitrate content of soils under various crops to rank as follows: Fallow, cultivated crops, grain crops, and virgin soils (grassland). Lyon and Bizzell (13) noted that the nitrate content of soil growing timothy was extremely low and fluctuated only slightly throughout the year. Hall (7) found that South African virgin grassland soils never contained in the course of a year's time more than 3 p. p. m. of nitrate nitrogen. That this was not due to lack of nitrifiable matter nor of a nitrifying flora was shown by the fact that 18 days after plowing the same soil contained 39.8 p. p. m. of nitrate nitrogen. Lyon, Heinicke, and Wilson (16) have demonstrated the decreased yield and vigor of apple trees growing in sod orchards to be due to the low nitrate level brought about by the grass. Not only is the nitrate content of grassland soils low, but added mineral nitrogen tends to disappear as such very rapidly (2).

The low nitrate content of grassland soils need not be attributed to any inhibitory action of the grass upon the process of nitrification in the soil. Doubtless assimilation by the grass in its growth is largely responsible for this. However, from the work of Leather (12), Russell (20), Lyon and Bizzell (14), Bizzell (2), and Porges (19) it would appear that not all the disappearance of nitrates in a cropped soil can be accounted for by the nitrogen found in the crop and in leachings. This discrepancy is especially marked in grassland soils. Loss of nitrogen due to denitrification would not be expected in grassland soils since favorable conditions necessary for this are usually absent.

Because of the heavy root growth of the perennial plants making up the grassland vegetation and its wide distribution in the surface soil, there is available to the soil micro-organisms a constant supply of organic matter. The assimilation of inorganic nitrogen in the presence of an energy source, as noted by Kruger and Schneidewind (9, 10), Doryland (4), and others, may then afford a partial explanation of the extremely low nitrate values found in grassland soils and the low loss of nitrogen from grassland as compared to cropped soils.

Snyder (22) found that soil which had been cropped continuously to wheat for 8 years had lost 21% of its original nitrogen. This amounted to a reduction of 1,100 pounds per acre of which only 300 pounds had been recovered in the crop. A considerable loss was found even though a crop rotation containing legumes was followed. Fallowing the land increased the loss. The greater loss of nitrogen under cultivated crops was attributed to its more rapid change into soluble and gaseous forms. Connor (3) and Swanson (26) have presented data from Indiana and Kansas soils showing the large losses of nitrogen and organic matter from cropped soils. Lyon and Bizzell (15) found a greater amount of nitrogen leached from soils under fallow or cultivated crops than from soils under grass. Hall (6) has reported for a Rothamsted soil growing grass with no legumes an accumulation of 25 pounds of nitrogen per acre per year over a period of 20 years.

Lyon and Wilson (17) found in grass plats on which grass had been cut and allowed to remain an increase of 415 pounds of nitrogen per acre in the course of 11 years. Similar plats on which various green manure crops had been plowed under lost nitrogen, the amount of the loss being in every case directly proportional to the maximum nitrate accumulation in the soil.

EXPERIMENTAL

The studies reported here on a soil under both pasture and fallow conditions deal with the seasonal nitrate accumulation, nitrate accumulation from the soil organic matter and from ammonium sulfate, carbon dioxide production, and numbers of micro-organisms present in the soil. The work was carried out on field plats laid out in a permanent pasture, the bare plats being kept free of vegetation by scraping with a hoe. The pasture was an example of an excellent humid region pasture. A heavy sod had been formed consisting principally of Kentucky blue-grass and white clover, together with some orchard grass, red top, and a few weeds. No fertilizer treatments were applied to the plats during the course of the experiment nor during the previous 6 years.

Nitrate and moisture determinations were made upon the soils at intervals of 2 weeks during the growing seasons of 1928 and 1929. Carbon dioxide evolution studies were carried out at less frequent intervals in the apparatus employed by Waksman and Starkey (28). Total numbers of micro-organisms were determined by the plate

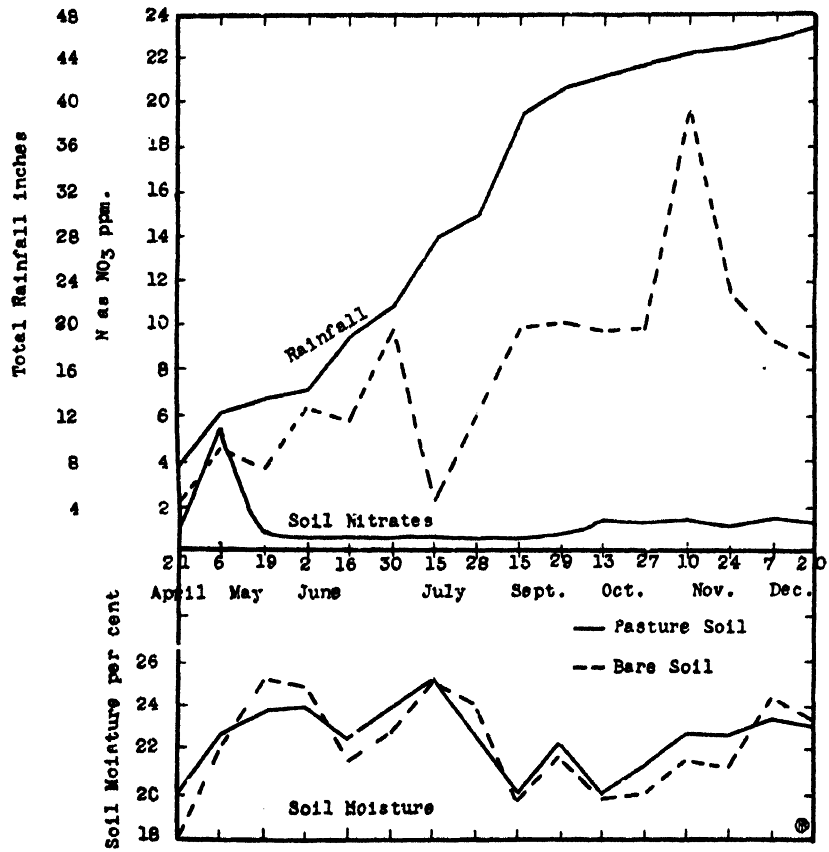

FIG. 1.—Nitrate accumulation, soil moisture, and rainfall in pasture and bare soils, 1928.

method using the synthetic media recommended by Fred and Waksman (5). Numbers of the *B. radiobacter* group of bacteria were determined by using the method of Smith (21). The ability of the bare and pasture soils to nitrify the soil nitrogen and also ammonium sulfate was determined by the methods suggested by Waksman (27). The total nitrogen and carbon contents of the soils were determined at the end of the experiment in September, 1929.

NITRATE ACCUMULATION IN THE FIELD SOILS

The nitrate accumulation in the field soils of the bare and pasture plats throughout the seasons of 1928 and 1929 are given in Figs. 1 and

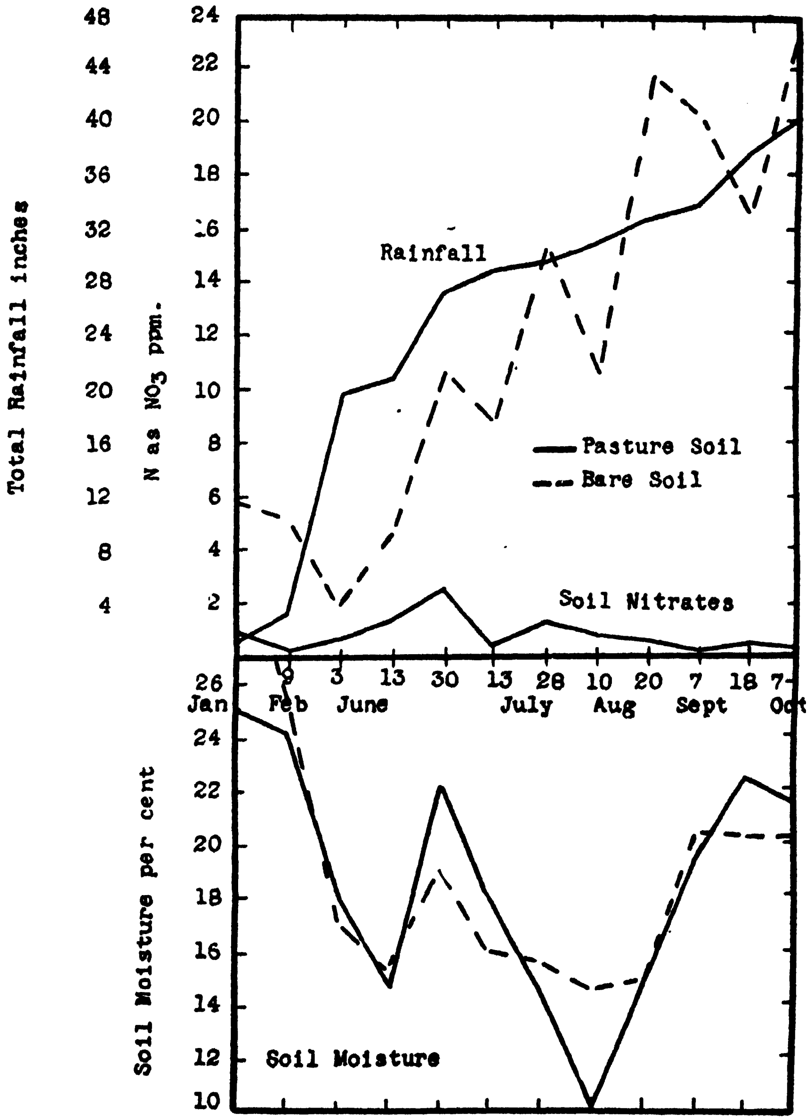

FIG. 2.—Nitrate accumulation, soil moisture, and rainfall in pasture and bare soils, 1929.

2. In the same figures are included the soil moisture contents and the total rainfall at the time of sampling.

It will be noticed that in 1928, with data for the month of August missing, the nitrates began in the bare soil at a very low level in April and gradually rose, until a maximum was reached in the first part of November. Following this there was a rapid drop in nitrate content during the winter months. The low nitrate content on July 15 was due to the leaching effects of a rain of 2.13 inches on July 13. There seems to be no correlation between nitrate accumulation and soil moisture. The moisture content of the soil remained at fairly high levels and did not at any time become sufficiently low to interfere with nitrification. There is found a correlation between the curves for nitrate accumulation and accumulated rainfall, particularly during the period up to October 13. The maximum rise in nitrates, however, occurred after the rainfall had begun to drop off in the late autumn.

In the pasture plats, low values for nitrate accumulation were found, a phenomenon usually associated with grassland soils. Beginning on April 21, with a nitrate content below that of the bare plats, there was a rise at the next sampling period, namely, May 6, equaling that in the bare plats. From this time there was a drop to a level where nitrates could scarcely be detected by the phenoldisulfonic acid method. There was a slight rise in the autumn continuing throughout the rest of the season. With the exception of the results obtained on May 6, when 5.48 p. p. m. of nitrate nitrogen were found, the values scarcely exceed 1 p. p. m. during the year. The fluctuations consequently were so small as to be insignificant.

The general trend of nitrate accumulation in both soils during 1929 resembled that of 1928. Nitrates in the pasture soil during the early part of the season were slightly higher in 1929 than in 1928, but did not reach appreciably large amounts. In the bare soil there was a fairly uniform rise in nitrate content from the beginning of the season until October.

It was not possible in a field experiment of this nature to measure all the factors affecting nitrate accumulation in the two soils. It is reasonable to believe that there was little or no nitrate reduction in either soil since they were well aerated, since there was no excess of readily decomposable organic matter, and since the amount of nitrate present was comparatively small. Determinations of ammonia by the method of Bengtsson (1) at various times during the experiment never revealed appreciable amounts of this form of nitrogen in either of the two soils. Leaching was probably of some importance. It has been shown (15) that the loss of nitrate by leaching is greater from uncropped than from cropped soils and is particularly small from

soils cropped to grasses. If leaching had not taken place, it is probable that the differences in nitrate accumulation in the pasture and bare plats would have been accentuated due to a higher accumulation of nitrate in the bare soil. Except during the early part of August, 1929, there was very little difference in the moisture content of the two soils. As a matter of fact, the moisture content of the pasture soil usually equalled or exceeded that of the bare soil.

The nitrate accumulation curve for the bare plats is similar to that usually found in bare or fallow soils and is generally ascribed to the effect of seasonal climatic conditions. Since Starkey (25) has found evidence tending to show that the readily available organic matter in a soil is decomposed in the course of a single season, it is possible that a part of the higher nitrate accumulation late in the season is due to nitrification of bacterial nitrogenous complexes in the soil. The very rapid rise in nitrates found in this experiment during the autumn, particularly in 1928, would point to the becoming available of a source of organic matter containing considerable quantities of forms of nitrogen readily mineralized.

The extremely low nitrate accumulation in the soil of the pasture plats need not be ascribed to a depressed formation of nitrates, but is no doubt due largely to the absorption of nitrogen by the extensive root system, with the assimilation of some of the nitrogen by soil organisms utilizing as an energy source the organic matter left by the plants playing an as yet unmeasured part.

The effect of the grass upon the ability of the soil to nitrify its own nitrogen, as well as that in ammonium sulfate, is shown in Table 1. In the case of the ammonium sulfate, the nitrate due to nitrification of the soil nitrogen has been subtracted from the total nitrate found. The nitrogen in the soil from the pasture plats is seen to be nitrified to the extent of 1.45% in 4 weeks, while 1.07% of the nitrogen from the uncropped soil appears as nitrate. As measured by the nitrification of ammonia sulfate, the bare soil seemed to be slightly more active. The greater drop in pH of the pasture soil during the 4

TABLE 1.—*Nitrification of soil nitrogen and of ammonium sulfate in soil from bare and pasture plats.*

Soil	Soil nitrogen			Ammonium sulfate		
	Mgm N as NO_3 per 100 grams dry soil	Percentage total soil N appearing as NO_3	Mgm N as NO_3 from $(NH_4)_2SO_4$	Percentage added N nitrified in 4 weeks	pH at beginning	pH at end
Pasture	1.804	1.45	5.58	18.60	6.5	5.67
Bare	1.202	1.07	6.67	22.23	6.2	5.82

weeks of incubation may account for this lower nitrate accumulation. Obviously, the pasture soil possesses as active a nitrifying flora as does the bare soil, and the low nitrate content under grass in the field cannot be ascribed to a lack of the proper organisms.

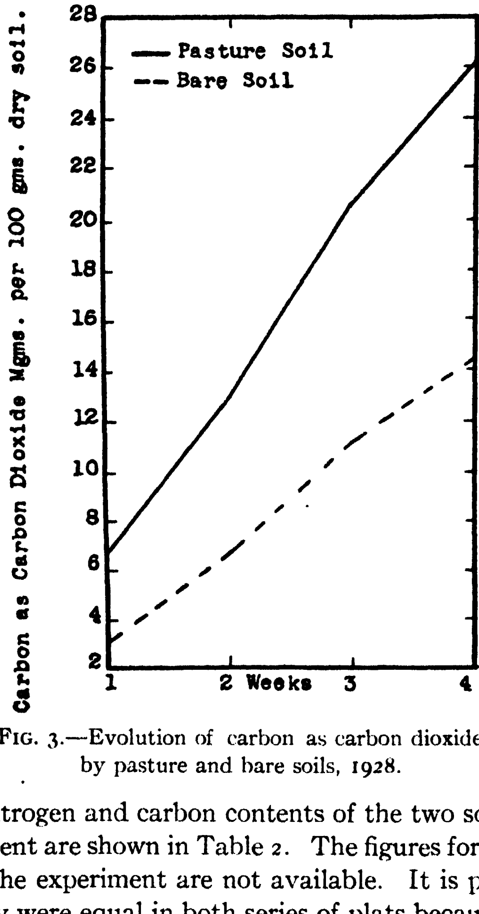

FIG. 3.—Evolution of carbon as carbon dioxide by pasture and bare soils, 1928.

The total nitrogen and carbon contents of the two soils at the end of the experiment are shown in Table 2. The figures for the soil at the beginning of the experiment are not available. It is probable, however, that they were equal in both series of plats because of the close proximity of the plats and the agreement between plats of the same treatment at the end of the experiment. After 2½ years without growing plants, the bare soil contained 0.012% less nitrogen and 0.07% less carbon than did the pasture soil.

TABLE 2.—*Total nitrogen and carbon in bare and pasture soils at end of experiment.*

Soil	N, %	Pounds N per 2,000,000 lbs. of soil	C, %	C/N ratio
Pasture	0.1241	2,482	1.484	11.9
Bare	0.1121	2,242	1.414	12.6

CARBON DIOXIDE EVOLUTION

The carbon dioxide evolved from the pasture and bare soils when placed under optimum laboratory conditions is shown in Fig. 3 and 4. The pasture soil produced carbon dioxide at a higher rate than did the bare soil, both in 1928 and 1929. During a 4 weeks' period of

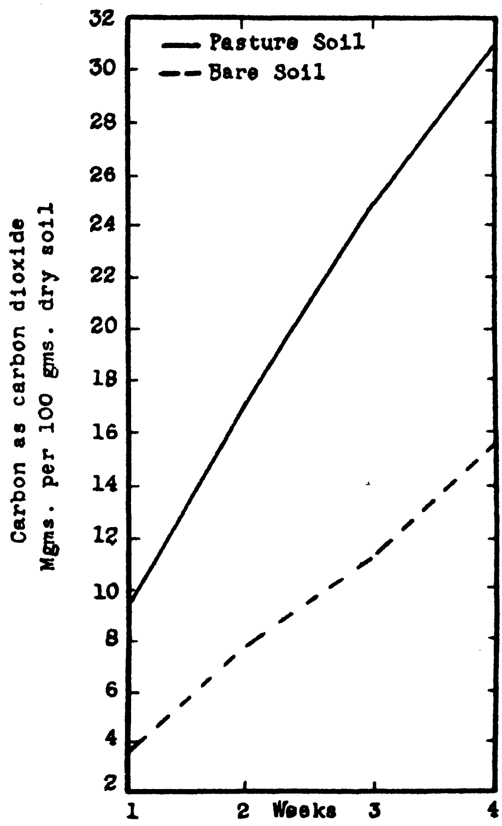

FIG. 4.—Evolution of carbon as carbon dioxide by pasture and bare soils, 1929.

1928 there was a total production of 14.52 mgm carbon as carbon dioxide from the bare soil and 26.09 mgm from the pasture soil. In 1929 the corresponding values were 15.6 mgm and 30.1 mgm carbon as carbon dioxide for the bare soil and pasture soil, respectively. These results indicate clearly a greater microbial activity and a larger amount of readily decomposable organic complexes in the pasture soil.

NUMBERS OF MICRO-ORGANISMS

The numbers of micro-organisms, as determined by the plate method, found in the soil of the two series of plats are given in Table 3. There is no significant difference in the total numbers of micro-organisms found in the pasture and bare soils as determined by the plate method. It is realized, however, that because only a few of the total number of soil organisms can develop on the media used, caution must be exercised in drawing definite conclusions from these data. That there are differences in the numbers of the physiological groups present is indicated by the numbers of actinomyces, fungi, and the *B. radiobacter* group. The pasture soil contained larger numbers of all these three groups of organisms than did the bare soil. It is to be recalled that these three groups of organisms are active in the decomposition of plant residues. When these results are compared with the higher CO_2 evolution in the pasture soil, they become quite significant.

TABLE 3.—*Number of micro-organisms in the soil of the bare and pasture plats per gram of dry soil.*

Soil	Bacteria, millions	Actinomyces, millions	Actinomyces, %	Fungi, thousands	*B. radiobacter*, thousands
			October, 1928		
Pasture...	5.75	2.13	27.0	27.06	—
Bare.....	5.96	2.04	25.5	22.66	—
			September, 1929		
Pasture...	3.75	3.19	45.9	20.94	314.28
Bare.....	4.19	2.39	36.2	19.83	149.90

SUMMARY

A soil under permanent pasture conditions and the same soil kept free of vegetation were studied from the point of view of microbiological factors of seasonal nitrate nitrogen accumulation under field conditions, accumulation of nitrate from the soil organic matter and from ammonium sulfate, rate of carbon dioxide evolution, and numbers of micro-organisms. The results can be summarized as follows:

The soil growing pasture grasses had an extremely low and almost constant nitrate content. The same soil without growing plants accumulated considerable quantities of nitrate, the amount of which exhibited a seasonal fluctuation which seemed to be correlated with the accumulated rainfall. There is evidence also that part of the autumn rise in soil nitrate may be due to mineralization of nitrogenous microbial complexes.

The nitrate accumulation from the soil organic matter was 35% greater in soil from pasture plats than in soil from bare plats. A slightly greater nitrification of ammonium sulfate was found in the bare soil than in the pasture soil. The low nitrate values in the grass soil were not due to a lack of nitrifiable organic matter or of a nitrifying flora.

The production of carbon dioxide from the pasture soil was on the average 194% of that from the bare soil. This indicates a much greater microbiological activity in the pasture soil.

Significant differences in total numbers of micro-organisms as determined by the plate method were not found. Fungi and actinomyces were more numerous in the pasture than in the bare soil. The *B. radiobacter* group was twice as numerous in the pasture as in the bare soil.

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CROP YIELDS IN RELATION TO RESIDUAL SOIL ORGANIC MATTER[1]

J. W. WHITE[2]

The ultimate accumulation of soil organic matter under field conditions depends primarily upon the nature of the cropping system followed. It is well known that soils in permanent grass invariably contain a higher proportion of organic matter than similar soils in a system involving soil cultivation. Advantage of this fact is recognized in the manner of planning grain rotations to alternate the periods of cultivation with a period in grass and leguminous crops. Thus, in the four-year grain rotation followed on the old fertilizer plats of the Pennsylvania Station, there is a period of 33 months from the time of seeding wheat and grass until the sod is plowed for corn when the soil is left undisturbed. During this rest period there occurs a pronounced accumulation of soil organic matter which tends to balance that lost as the result of soil cultivation. Through a period of years, therefore, there is established, in such a rotation, an economic balance or equilibrium between the organic matter lost as the result of cultivation and that gained during the time the soil is left undisturbed in clover and timothy sod.

The Pennsylvania field plats offer an excellent opportunity to study the relation of yields to residual organic matter since there are included 24 different treatments which have been continued for a period of 49 years. The present study deals with each of these differently treated plats, including a period of 40 years during which the experiment has been conducted without change of plan. In this old field plat experiment the fertilizers and manure are applied to corn and wheat. Limestone is applied to each corn and wheat crop of plat 34 at the rate of 2 tons per acre, as compared to 2 tons of burnt lime applied to each corn crop of plat 23. Land plaster is applied at the rate of 320 pounds per acre to each corn and wheat crop of plats 13 and 33. The rotation followed is corn, oats, wheat, and hay (mixed clover and timothy). All harvested crops are removed from the plats, therefore, the soil is dependent upon crop residues (roots and stubbles) as the only source of organic matter with the exception of those plats which receive barnyard manure.

[1]Contribution from the Department of Agronomy, Pennsylvania Agricultural Experiment Station, State College, Penn. Also read as part of the symposium on "The Nature of Soil Organic Matter and Its Relation to Soil Fertility" at the meeting of the Society held in Washington, November 21, 1930. Received for publication January 21, 1931.

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If it is assumed that the roots and stubbles are returned to each plat soil in amounts proportionate to the respective yields, then we would expect to find that there exists a definite relationship between yields and residual soil organic matter, in the case of each treatment, provided that the respective manurial treatments have had the same stimulating influence on the decay of soil organic matter.

It has been shown by various experiments, however, that fertilizer materials, such as nitrogen and phosphorus, each have a pronounced effect in stimulating vegetable decay. On this basis, therefore, even if the proportionate crop residues are returned to the respective plats, the rate of crop yields to the residual soil organic matter would vary in accordance with respective fertilizer treatments. This should be especially true in case of an experiment which has been conducted for many years where the nature and amounts of residual organic matter present should be independent of that present at the beginning of such an experiment.

RATIO OF YIELDS OF AIR-DRY MATTER TO RESIDUAL SOIL ORGANIC MATTER

As a means of studying the relation of yields to soil organic matter, the pounds per acre of organic matter (C X 1.724 X 2,000,000) present at the end of 40 years of experiment were divided by the total yields of air-dry matter produced during the 40-year period. Table 1 shows such a ratio expressed in pounds of soil organic matter per ton of air-dry matter harvested. Columns 3 and 4 show the relative yields of air-dry matter and soil organic matter expressed in terms of the untreated plats taken as 100.

A study of the data in Table 1 brings out some interesting relationships between yields of crops and residual organic matter established at the end of 40 years of continuous experiment. In every instance where the treatments have produced relatively low yields, less than an increase of 20% over the check soil, the soil organic matter is relatively high. The first six plats show an average ratio of 912 compared to 762 for the average of the remaining plats. This difference in ratio between the low- and high-yielding plats is no doubt due to the influence of the respective treatments on the stimulation of the activity of soil micro-organisms. In each instance where phosphorus is applied, the ratio is low. The NK treatment shows a ratio of 878 compared to 698 for NP. Nitrogen has also stimulated organic matter decay but to a much lesser degree than the phosphorus treatment. This is shown from a comparison of the PK treatment with PKN, the averages being 654 and 679, respectively.

It is of interest to note the effect of the three carriers of nitrogen on the organic matter ratio. The average ratios for nitrate of soda, dried blood, and sulfate of ammonia are 631, 681, and 719, respectively. This difference is no doubt due to the controlling influence of soil acidity on the activity of the soil micro-organisms.

TABLE 1.—*Relation of yields to residual soil organic matter.*

Plat treatment	Yield-organic matter ratio*	Untreated soil as 100	
		Plat yields	Soil organic matter
N (24 lbs. N, dried blood)	916	99	91
Untreated	992	100	100
K	958	100	97
Land plaster	892	104	93
Burnt lime	932	111	104
KN (24 lbs. N, dried blood)	878	112	99
Limestone	818	120	99
P	762	126	97
PN (24 lbs. N dried blood)	698	144	101
PK+72 lbs. N (ammonium sulfate)	770	146	113
PK+48 lbs. N (ammonium sulfate)	718	159	115
PK+24 lbs. N (dried blood)	716	163	118
PK+24 lbs. N (ammonium sulfate)	668	164	110
PK	654	175	116
PK+24 lbs. N (nitrate of soda)	664	176	117
PK+48 lbs. N (nitrate of soda)	614	181	112
PK+72 lbs. N (dried blood)	650	181	119
PK+72 lbs. N (nitrate of soda)	616	184	114
6 tons manure	774	167	131
8 tons manure	764	172	132
6 tons manure+lime (CaO)	718	180	131
10 tons manure	760	181	138

*Organic matter ratio = Pounds organic matter per ton of total air-dry matter produced in 40 years.

The lime requirements ($CaCO_3$) of these three soils are 2,787, 4,790, and 5,800, respectively. The four manure treatments show similar ratios in spite of the fact that the amounts of manure vary in three instances. The plat soil which has received a total of 200 tons of manure in 40 years, equivalent to 40 tons of organic matter, contains only 38% of organic matter in excess of the untreated soil. This fact serves to emphasize the rate of organic matter decay on this soil which is of limestone origin. From the data shown in this table we may conclude that in case of similar treatments there exists a close ratio between the productivity of the soil and the residual soil organic matter. These data show further that in case of each treatment which includes phosphorus there exists a relatively low ratio of soil organic matter.

In order to gain further information concerning the causes of differences in organic matter ratios between the high- and low-yielding plats, a study was made of the rate of organic matter decay of each differently treated soil. Soils representing each treatment were incubated at laboratory temperature for a period of two weeks. At 24- and 48-hour periods the CO_2 was collected in the usual way involving soil respiration studies. Each soil was treated with water in amounts sufficient to supply 55% of its water-holding capacity. Table 2 shows the results secured, including both the untreated soils and those which received 0.5% of cellulose.

TABLE 2.—*Yield-organic matter ratios in relation to soil respiration.*

Plat treatment	Yield-organic matter ratio	Milligrams CO_2 per 250 grams soil, total for 14 days	
		Soil	Soil plus cellulose
Untreated	992	205	543
Burnt lime	932	173	461
Land plaster	892	188	500
Limestone	818	173	532
NK (24 lbs. N)	878	210	567
P	762	283	626
PN (24 lbs. N)	698	305	685
PK	654	276	734
PKN (24 lbs. N, nitrate of soda)	664	299	717
PKN (24 lbs. N, ammonium sulfate)	668	279	626
PKN (24 lbs. N, dried blood)	716	266	633
6 tons manure	774	265	621
6 tons manure + lime	718	258	860
Averages:			
First 5 treatments	902	190	521
Second 8 treatments	707	279	688

From the data in Table 2 it may be concluded that the low organic matter ratio is associated with soils the treatments of which cause a stimulation of organic matter decay considerably in excess of the low-yielding plats. This conclusion seems justified from data furnished by both the untreated soils and those which received cellulose.

CONCLUSIONS

1. On similarly treated soils there exists a close ratio between the total yields of crops and the residual soil organic matter.

2. Soils of a relatively low productivity contain a higher proportion of soil organic matter to yields of air-dry matter than is true of more productive soils. This relationship is shown to be as

follows: The 7 treatments which gave an average yield of only 8% in excess of the check plats show a ratio of 912 pounds organic matter per ton of air-dry matter compared to an average ratio of 681 for 11 plats which show an average yield of 64% in excess of the untreated soil. The four manure plats, which gave an increased yield of 75%, show an organic matter ratio of 754.

3. The differences in organic matter ratios between soils of high and low productivity are due to the fact that the manurial treatments which stimulate the production of the higher plants also encourage a more vigorous growth and activity of soil micro-organisms associated with the decay of soil vegetable matter.

4. The influence of soil conditions on the yield-organic matter ratio is brought out by a study of the plat soils which receive the three carriers of nitrogen. The relation of soil acidity to the organic matter ratio is as follows:

Average of 3 plats	Lime requirement	Yield-organic matter ratio
Nitrate of soda	2,787	631
Dried blood	4,790	681
Ammonium sulfate	5,800	719

5. The figures which represent the yield-organic matter ratio were obtained for each treatment by dividing the pounds per acre of residual soil organic matter by the total pounds of air-dry matter produced in 40 years. The figures given in Tables 1 and 2 represent the pounds of organic matter per ton of air-dry matter produced. These figures, such as 902, 654, etc., are purely arbitrary and apply only to this period of the experiment. This is obvious from the fact that the pounds of soil organic matter remain fairly constant and at the same time the yields of crops are cumulative.

CULTURAL CHANGES IN SOILS FROM THE STANDPOINT OF EROSION[1]

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Cultural operations as they shall be construed in this paper have been directly or indirectly responsible for changes in the soils of the United States to a degree which greatly exceeds the general conception of most of us, soil scientists, as well as others. It must be admitted at the outset that we have not yet accumulated sufficient data of a quantitative nature to present a full and accurate statement of these cultural changes. We have, nevertheless, collected enough data for at least a generalized appraisal of some of these changes and their significance in relation to agricultural practice and crop production.

To avoid any misunderstanding of the measurements, estimates, and interpretations presented in this paper, it will be well at the outset to define the terms "the soil" and "cultural changes" as here used. "The soil" refers to the soil profile or vertical section extending from the surface of the ground down into and including the upper part of the substratum of parent material. Differentiation between the definite natural layers or horizons through this vertical section will be made either by the use of such terms as *topsoil* or *surface soil subsurface*, *subsoil*, and *parent material*, or by direct characterization of the materials corresponding to the specific depths limiting the successive natural layers down through the profile.

"Cultural change," as employed here refers to any obvious change, either physical or chemical, in the original or virgin soil condition that may be found to represent, unmistakably, the direct or indirect result of man's activities. Those changes which have come about through the instrumentality of erosion induced by such activities will be emphasized. Chiefly, these consist of bodily removal of part or all of any of the soil layers, and of textural or other alterations in the surface soil by such processes as mixing, overwashing, and elutriation. The principal causes and processes involved in such changes are: (a) Removal or destruction of vegetation by axe, plow, livestock, and fire; (b) disturbance or complete destruction of the normal ground structure or alteration of the texture by culti-

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Also, presented as a part of a symposium on "Cultural Changes in Soils," at the joint meeting of the Society and the American Soil Survey Association, held in Washington, D. C., November 20, 1930. Received for publication December 9, 1930.

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vation or trampling of livestock; (c) removal of the soil material, bodily or selectively, by running water or wind; and (d) changes brought about at the surface by such erosional activities as mixing, overdepositing, and clogging of the soil pore spaces with fine particles washed down from above.

It may be helpful to a better understanding of these changes to bear in mind two pertinent facts, *viz.*, that rainwater flowing from the surface of cultivated fields occupying the principal classes of American farm lands is never actually clear; and, conversely, that essentially clear rainwater does frequently flow from areas occupied by good stands of unburned timber, or by those grasses and herbaceous growths which more or less completely cover the surface of the ground. In recognizing these differences and their significance, one gets a fairly clear conception of what shall be considered as *normal* or *natural erosion*, on the one hand, and *abnormal* or *unnatural erosion*, on the other hand. It is with the latter type of erosion, the man-induced kind, that this discussion is chiefly concerned.

LARGE EXTENT OF LAND SUBJECT TO EROSION

On the basis of topographic maps, soil surveys, and observation, it appears reasonably safe to put the area of land having slopes as steep as or steeper than the plats at the Spur Substation of the Texas Agricultural Experiment Station,[3] as amounting to not less than 75% of all the cultivated land of the continental United States. At this substation, from land having a 2% slope and subjected to a mean annual precipitation of approximately 21 inches, the average yearly removal of soil by erosion amounts to 18.6 tons per acre from fallow ground, 12.6 tons from continuous cotton, and 3.8 tons from buffalo grass sod. In 1926, 27.99 inches[4] of rainfall removed 40.7 tons of soil per acre from fallow ground and 27.9 tons from cotton. The corresponding average annual losses of water were 32.6% of the rainfall from fallow, 19.5% from cotton, and 6.1% from sod. The maximum annual losses ranged up to 48.7% from fallow and 28.2% for cotton ground, in 1926.

Again, it appears reasonably safe to estimate the area of cultivated land in the United States having gradients equal to or in excess of 3.6%, representing the slope of the plats on which soil and water losses have been measured at the Missouri Agricultural Experiment

[3]Situated in the western part of the Red Plains, near the eastern part of the High Plains (staked plains).

[4]Precipitation for the period June 18 to Dec. 31, 1926.

Station,[5] as aggregating between 60 and 65% of the total land area in cultivation. With an average precipitation of approximately 36 inches, the 12-year average loss of soil by erosion from these Missouri plats amounted to 44.4 tons per acre, annually, from fallow ground (cultivated 4 inches deep); 20.5 tons from continuous corn; and 0.35 ton from bluegrass sod. The corresponding losses of the rainfall, by runoff, were 32.63% from fallow ground, 32.02% from continuous corn, and 14.21% from sod.[6] From plats occupying an 8% slope, the losses of soil have been much greater.

The soils on which these measurements were made are extensive and important agricultural types, *viz.*, the Miles clay loam in Texas, a very important cotton and grain sorghum soil; and the Shelby loam in Missouri, an important corn soil in northern Missouri, southern Iowa, southeastern Nebraska, and northeastern Kansas.

All of the cultivated land of the nation having slopes equal to or greater than the Texas and Missouri soils on which these experiments were carried out is subject to unnatural erosion in some degree. It is not all so erosive as these types and some of their close relatives; but, unfortunately, some of it is even more erosive.

EROSION IN THE PIEDMONT COUNTRY

In the Piedmont region, observation and soil surveys indicate that in the neighborhood of 65% of the area which has been or is now under cultivation has lost from around 4 to 18 inches, or more, of its soil and subsoil. Moreover, probably not less than 50 to 60% of all the formerly cultivated alluvial land in the lower stream bottoms of that region has been covered by erosional débris to depths ranging from a few inches to more than 6 feet. Much of the overwash now covering the original soil consists of sand and gravel, often loose and almost invariably much lower in productiveness than was the heavier, darker colored alluvial soil beneath, that is, the original alluvial soil, as it existed at the beginning of agricultural operations in the Piedmont. The deposits are so variable in texture and other characteristics, within narrow limits, that it has been impossible, generally, to make satisfactory soil-type separation of the numerous conditions on soil maps. Accordingly, much of this land has been classed and mapped as "meadow."

Besides the serious damage resulting from these man-induced overdeposits, the drainage conditions have been made exceedingly bad, in most instances, by the increased frequency and duration of overflows resulting from choking or partly filling of the stream channels.

[5]Located on glacial soil (Shelby loam) in central Missouri.

[6]Data supplied by Prof. M. F. Miller, University of Missouri.

This rapid and excessive deposition of erosional débris has followed the inception of agriculture in the region. The result has been that a very large proportion of these alluvial lands has been wholly changed from the original soil condition. These profound modifications of the bottom lands particularly characterize the smaller streams, though the broader bottoms of the major waterways have been largely affected also.

Such changes are by no means restricted to the Piedmont region; indeed, a common characteristic of a large proportion of the stream-bottom soils of the humid United States, as well as many of those of the less humid regions to the west, is the presence of recently deposited soil material of a distinctly different nature from that which characterized these areas at the time of agricultural settlement. We find, for example, brown soils overlying the black alluvial soils that existed at the outset of agricultural occupation, such as the Ray soils now being mapped in the north central states. Literally, thousands of streams are bordered by long stretches of light-colored sand overlying dark-colored silt loams and clays of the pre-agricultural stage. It is a simple matter, usually, to get the local history of these alluvial-land modifications. They definitely represent changes contemporaneous with the period of local land utilization by the white man.

There is little doubt but that any experienced soil scientist who critically examines, for example, the lands of Union County, South Carolina, will find, especially with the aid of the soil map and report covering that area published by the Bureau of Soils (4),[7] that not less than 125,000 acres, amounting to 40% of the area of the upland soils of the county, have lost largely or entirely the original topsoil. The Cecil clay loam, comprising 70,912 acres, is a product of man-induced erosion which has taken place since farming began in that locality. It is a new soil type, created by the washing off of the original sandy loam and loam surface soil. This was the conclusion of those who made the soil survey of the county; and there is abundant evidence that it is the correct conclusion. Practically all of the area occupied by this type is now or has been in cultivation. Every heavy rain sweeps away a part of the surface material.

Of the 24,768 acres of alluvial land mapped in Union County, 20,352 acres, amounting to 82% of the total of alluvial land, consists of meadow, a highly variable soil formed by erosional overwash since the beginning of agricultural operations. The soil men who

[7]Reference by number is to "Literature Cited," p. 454.

surveyed the county have the following to say of the area classed as meadow:

"Probably at one time the material of these bottom lands was fairly uniform, consisting of a dark-brownish loam to sandy loam; but since the uplands have been cleared, erosion has been active, and this eroded material, consisting largely of sand, has been distributed over these bottoms. This deposition has resulted in wide, textural variations, the material, ranging from sand to loam and silty clay loam, being so intermingled that as a rule it can not be separated."

Union County is fairly typical of many other Piedmont counties. The same thing has happened in a large majority of the others, even on a much more extensive scale in some of them. In a neighboring county (1), 90,560 acres, or 18.7% of the total area, were classed and mapped as rough gullied land and defined as being largely without agricultural value. Most of this was formerly cultivated and considered good soil. This profound change by no means represents the full effects of erosion in the area surveyed. For example, 54,272 acres were mapped as meadow, most of which, though originally good agricultural soil of the Congaree series, has been covered with overwash, chiefly sand, and thus rendered almost worthless insofar as cultivation is concerned. In addition, the other upland types have been seriously changed and damaged by excessive washing to degrees ranging from about 10 to 75% of their individual areas.

In nearly every county of the Piedmont region, with its 50 million acres of land, more or less soil has been abandoned because of erosion; and other areas, still in cultivation, have nothing, or but little, of the surface soil left.

Such changes are not restricted to the Piedmont. Some of the other major agricultural regions of the country have undergone even more rapid and extensive soil modification, often amounting to almost complete devastation.

SOIL CHANGES IN THE BLACK BELT

The soil survey of Lowndes County, Alabama (7), shows that 56,192 acres, amounting to 12.4% of the area of the county, consist of Sumter clay. There is evidence that nearly all of this greenish-brown, limey soil represents the subsoil of the dark-colored Houston clay, exposed through the effects of sheet erosion since the beginning of agriculture in the Black Belt. The yields of cotton prior to the advent of the boll weevil, as given in the soil survey report, were ½ to 1 bale per acre from the Houston clay and 1/3 to ¾ of a bale from the Sumter clay. While this is not an extreme change in pro-

ductivity, it is, nevertheless, an indication of the downward trend in yield corresponding to the progression of erosion.

This type of soil change is characteristic of the Black Belt of Alabama and Mississippi. It is also characteristic of the rolling parts of the much larger Black Belt of Central Texas.

The soil survey of Rockwall County, Texas (3), shows 13.6% of the total land area mapped as the eroded phase of the Houston clay. Of the uplands of the county, this amounts to 17%. From most of this the dark-colored soil of the original type is gone, and in places the yellowish-brown or greenish-brown clay beneath the surface soil is gone also, down to the cream-colored parent chalk. The yields for the normal Houston clay of the locality, as given for years of average seasonal conditions, are ¼ to 2/3 of a bale of cotton and 30 to 45 bushels of corn per acre, and for the eroded phase of that type, 1/6 to 1/3 of a bale of cotton and 10 to 30 bushels of corn.

Since the beginning of agriculture in the rolling parts of the Black Belt of Texas, the soil condition has changed from that of an almost universally black land country to a country which in many localities is spotted black, brown, and white. Originally, there were white areas on the eroded escarpments of streams and a few of the steeper slopes elsewhere, but generally the region was as stated. In a few more generations, the condition of these rolling black lands is destined to be that of a prevailingly whitish soil, representing the exposed parent chalk, with only patches of the original black land remaining here and there. Even the deep black soils of the overflowed bottoms will be changed largely to gray soil by overwash from the de-surfaced uplands. Indeed, this has already happened in many places. This assertion is not so much a prediction as a mathematical certainty based on the depth of the soil and subsoil down to the whitish chalk and the rate of erosion—that is, unless successful measures of erosion control are widely adopted by the farmers.

The yields referred to above for the eroded phase of the Houston clay do not give the full measure of the progressively impoverishing effects of soil erosion in this region. Many Black Land farms having erosional areas of chalk are producing on such areas from about 1/10 to 1/20 of a bale of cotton per acre. In 1929, the yield reported from severely eroded fields on a large farm between Temple and Waco, Texas, was given at about 1 bale of cotton from 40 acres of land. In other words, the cotton had suffered so severely from dry summer weather following wet spring weather that not enough was produced on these severely washed lands to warrant harvesting. In the same year, however, on the same farm in the neighborhood of

½ bale of cotton per acre was produced in some of the fields where the original covering of black soil had not been completely washed off.

Again, in 1930, with unfavorably dry summer weather, the same devastated lands gave only insignificant yields.

To give some quantitative expression of what is going on in this region, a single measurement made this year by G. W. Musgrave at the Temple, Texas, Soil Erosion and Moisture Conservation Experiment Station may be cited as follows: Erosion caused by a single rain, which fell on the morning of May 10, washed from the Houston black clay, planted to cotton, rich surface soil material at the rate of 23 tons per acre, with an accompanying loss of 96% of the rainfall. This heavy rain fell over an area of similar Black Belt land amounting to probably not less than 3 million acres, severely washing every acre of it that was not adequately protected by field terraces and most of it was not thus protected. Even flat areas, including some alluvial plains, suffered from direct erosion. This rain amounted to approximately 5 inches, most of it falling between the hours of 7 and 11 o'clock. A similar rain fell at about the same time in 1929, and likewise did vast damage to the same area through the vicious effects of sheet erosion.

It is possible to get a better conception of what this means in terms of soil impairment when one considers the fact that the average depth of the virgin sloping Houston soil is scarcely so much as 12 inches, and, further, that all the sloping fields of the region have been thinned down by the continuing washing, which began with the breaking of the prairie sod.

OKLAHOMA EROSION SURVEYS

This year Oklahoma completed an erosion survey of the state. This shows that of the 15,781,904 acres planted to crops in Oklahoma in 1929, 13,196,735 acres were suffering seriously from erosion, 5,726,452 acres having reached the stage of gulleying, with 374,000 acres so cut to pieces that it is impractical to get farm machinery over the gulleys. Of 1,694,377 acres of crop land abandoned durinb the past 5 years, 1,359,327 acres were abandoned because of erosion.[8]

The reconnoissance erosion survey now being made by H. V. Geig of the Bureau of Chemistry and Soils of the Brazos River drainage basin in Texas is revealing that much of that vast area is suffering costly erosional changes in soil impoverishment, much like those found in Oklahoma.

[8]Data supplied by the Oklahoma Agricultural Experiment Station.

A very accurate detailed erosion survey of an average farm in the rolling Red Lands near Guthrie, Oklahoma, made by F. W. Knobel of the Federal Soil Survey, shows that of 160 acres in the tract, 74 acres had been put into cultivation during the past 30 years, and that of this area, 68 acres, or 92% of all the tilled land, had lost from 3 to 96 inches of soil and subsoil. For example, 25½ acres had lost 8 inches of soil; 23 acres had lost 13 inches; 5 acres had lost 20 inches; 1¼ acres had lost 42 inches; and 1 acre had lost 5 feet of soil and subsoil.

There are approximately 36 million acres in this Red Plains region, lying principally in Texas and Oklahoma. Topographically, about half of it is much like the farm near Guthrie, and over this much the same thing has taken place on the average farm. It is difficult in the rolling Red Plains to find a sloping field which does not show exposed clay subsoil or gulleys, or both.

Much the same condition is met with over many parts of northern Missouri, southern Iowa, and in some localities of southeastern Nebraska and northwestern Kansas, that is, in the regions of the Shelby and related soils.

THE SHELBY SOIL REGION

The agricultural agent of a northwestern Missouri county last year was showing a party of soil scientists and agricultural engineers a number of farms which were being considered for the location of a soil erosion and moisture conservation experiment station. The very first soil boring made on the first farm inspected revealed yellow clay at the surface in a large sloping cornfield. Only a film of the original deep, dark-colored soil remained as scattered patches through the field. The soil was Shelby clay and shallow Shelby loam and clay loam (derived from glacial material), occurring as intricately associated patches; and the corn on it was estimated as likely to produce an average of not more than 20 bushels per acre.

Lying adjacent to this severely eroded slope, which, for the most part, had lost not only its topsoil, but its subsurface soil and part of its subsoil, was a pasture well sodded with bluegrass. In this, the original topsoil of dark mellow loam, rich with humus, was everywhere present. It averaged about 8 inches deep, and below it was a second horizon of brown loam which graded downward through yellow-clay loam into stiff subsoil clay, like that exposed in numerous parts of the adjoining cornfield. It might be remarked incidentally, but very pertinently, that the surface of the grass-covered slope stood fully 3 feet above the surface of the immediately adjoining

cornfield. Forty years of cultivation had brought about this profound change in the Shelby loam—an alteration which not only had removed 3 feet of soil and subsoil, but had reduced the productivity of the eroded area from approximately a 60- to 75-bushel per acre corn capacity to approximately a 20-bushel capacity. Many spots produce no corn whatever, some years.

When the agricultural agent was informed that the national erosion program was to emphasize soil conservation rather than soil reclamation, he instantly informed the committee that, under such circumstances, they had come just 10 years too late to find a suitable location in that part of the county.

Moreover, farms were examined in other counties of this region which had lost all of the richer, dark top layer of soil from fully half of their cultivated area. There are many localities here where hillside gulleys of recent development are essentially a characteristic feature of the landscape. Most of these gulleys begin to develop at about that stage of washing which marks the removal of the surface soil. This means, seemingly, that when the soil is gone, erosion in this part of the country speeds up, at least with respect to gulley formation. The same thing is true, also, of many other parts of the country.

SOIL CHANGES IN THE GRAZING REGIONS

During the past two generations tremendous changes have taken place in the vegetative and soil conditions over countless areas in the western and southwestern grazing regions, even where the rainfall is very low.

A detailed soil survey was made of the alluvial plain of the Rio Grande Valley, New Mexico, immediately above the head of water in the Elephant Butte Reservoir, in 1929, covering a strip approximately 40 miles long. In August and September of that year, the greatest flood of history swept down the Rio Grande, destroying towns, railways, and farm buildings, and depositing millions of tons of erosional débris over the surveyed area, much of which was under cultivation. Sand was deposited over clay soils, and vice versa. So vast were the changes, the area had to be resurveyed this year. The soils were completely changed over most of the surveyed area. With the measurements of the areas thus modified, together with the accompanying increases n soil depth, it was learned that this flood deposited something like 88½ million tons of soil material over the small area involved. The depth of the deposits ranged up to 7 feet near the head of the great artificial lake of Elephant Butte. No one knows how much material was laid down in the reservoir itself,

taking up space intended to impound water, not soil. The amount must have been enormous, judging by the fact that surveys already made have shown that about 20 thousand acre-feet of sediments are normally deposited in this lake every year.

The greater part of this eroded soil came down the Puerco and Salado tributaries of the Rio Grande. A reconnoissance of a considerable part of the drainage basin of the Puerco, northwest of Albuquerque, made this year, shows that practically all of the uplands outside the national forests are washing severely. Large areas of these overgrazed lands have lost the topsoil completely, with the exception of a few square feet about the base of an occasional cedar or pine tree whose thick branches have kept the animals off the diminutive areas of protected ground. In many places trees are to be seen where the lateral roots are entirely exposed, some of them standing above the surface of the ground. Contemporaneously, the regimen of the streams has been profoundly altered. Broad, yawning channels now thread nearly every valley that originally contained a strip of alluvium. Increased volumes of water rushing down from the enclosing highlands have cut out these new channelways through alluvial plains that formerly consisted of rich, well-grassed flats over which flood waters spread out and largely soaked into the ground. In places the Puerco has cut away its alluvial plain from the foot of the highlands on one side to the corresponding position on the opposite side of the valley. Occasionally, houses have toppled into this great channel, which in places is 60 feet deep.

There is abundant evidence that this has happened since the coming of the white man with his sheep, goats, cattle, and horses. Here, erosion has not only changed the soils of the uplands, vastly reducing their grazing capacity, but it is unceasingly cutting away the bottoms, the former agricultural lands of the Pueblos, and is even causing the development of migrating dunes.

A letter to the author from Thomas A. Field, of Field, New Mexico, July 1, 1930, is indicative of the changes that have taken place in recent times. This communication reads as follows:

"I came here Aug. 10, 1886, saw the Rio Puerco first about the 10th, in fact, crossed it with a large herd of cattle where now is the station known as Puerco. The river then was not very wide, nor was the channel deep, and there were vegas and marshes all along the valley. Now the river has washed deep and wide and the marshes have disappeared. I know more about the Alamosa or Rio Salado, which is about 40 miles south of the Puerco by road, and in Socorro and Catron Counties, is about 150 miles long and drains a very large and mountainous region. When I first came here in 1886 and went into the stock ranching business, there was no channel to speak of in these

valleys. The valley was covered with grass, shrubs and in many places groves of cottonwoods, and whenever it rained in the mountains the flats would be flooded and grass and everything grew fine. Now there is a wide, deep channel, cut from the source to the mouth of this river, which has not only taken away nearly all the cottonwood trees, but in some places has washed the houses, farms and orchards of some of the old-time Mexican people away. In some places it is from 10 to 30 feet deep and from 200 feet to one-fourth of a mile wide. Water runs a little at different places for from ½ to 2 miles, very shallow, sinking into the sand between the runs; and in some places there are dry stretches of from 5 to 15 miles in length. Our rainfall here is about the same as always, but owing to the big washes, the water does not penetrate the ground, only runs off down the arroyos, taking more of the soil every year. So, the stock-grazing capacity per acre here is only about 50% of what it was when I first came to the country."

Channel trenching, the scalping and gulleying of foothills and mountain slopes, and the development of new sand dunes, stupendous changes in the surface of the earth, are characteristic of a vast total area in the Southwest. These changes are the result of cultural operations—damage to and depletion of vegetation by overgrazing, followed by inevitable erosion with the coming of the sudden downpours so characteristic of the region. In order to restore anything like normal conditions, the few instances of protected areas that we have as a yardstick indicate that 25 years of partial or complete protection from grazing is the minimum requirement for numerous areas.

Another astonishing example of what it means to destroy the natural soil conditions without providing protective measures to check erosion, is to be seen in the bean-producing country of western California; as over the broad ridge bordering Los Pozos Valley on the south. Here, following a few years of cultivation, sheet erosion strips off the loamy surface layer, which is about 6 to 8 inches deep, down to an exceedingly poor and intractable clay. Following this stage, gulleys, or "barrancas," develop and extend rapidly down the slopes, fingering out toward the head. These arroyos have cut deeply into the soft, underlying shaly rocks on the steeper slopes, and down these sweep infertile débris of mixed soil and rock fragments to spread out over the highly productive valley lands. In places the valley farmers have set out along the slopes tamarisk and eucalyptus trees in attempts to restrain erosional accretion of deleterious materials. The farmers of the hills recently have introduced and put into general practice a system of strip-subsoiling which, though not entirely stopping the washing, has greatly reduced it. Even so, the farmers in the valley are discussing a plan for buying the vulnerable hill lands so that they may be taken out of

cultivation entirely and permitted to revert to wild vegetation, solely as a means of protecting their high-priced lowlands.

THE SIGNIFICANCE OF THE TOPSOIL

Although the nation has lost, so far as practical use for crops is concerned, not less than 17½ million acres of formerly tilled land, as the result of gulleying and deep sheet erosion, it is not this area of essentially destroyed land that constitutes the gravest effects of soil erosion, but, rather, the far greater area whose surface soil is being planed off by unceasing sheet erosion. From the standpoint of soil conservation, it is vitally necessary that we come to a better understanding of the full meaning of the important top layer of our soils, the humus layer, if you please.

The prevailing impression, especially on the part of those unfamiliar with the characterizing details of the soils of the country, is that the surface soil is much deeper than our surveys have shown it to be. The depth of this upper, humus-charged layer over the most extensive upland soils of the country is not several feet, as many think, but only about 6 to 10 or 12 inches in thickness, on the average. When this is washed off, as is happening over millions of acres, it may be stated without any fear of exaggeration that less fertile material is usually exposed. Erosion never improves the condition of upland soil, not the erosion that we are presently concerned with, at any rate.

This conception is not in conflict with the real understanding of those who cite instances of soil improvement by direct erosion. Such examples simply relate to long-time erosion, the geologic norm of erosion, which removes, for example, impervious, relatively unproductive, acid clay from more productive, deep-lying substrata consisting of lime-bearing material. Such erosion does improve the soil, of course; but we need not be concerned with it, since the process is too slow, with the possible exception of occasional insignificant areas, to have much bearing on the lives of those having to do with this present geologic period.

Erosion not only reduces yields, but in some instances lowers the quality of the products grown on the areas affected. The impairment goes even further in the case of numerous areas. Often, the exposed soil layers consist of raw clay lacking in humus and having such greater density and stiffness as seriously to impede drainage and to accentuate difficulties of tillage. Such land absorbs water slower than did the mellow topsoil, and loses it faster with the baking and cracking effects of dry weather. Not only this, but rainwater usually flows away faster from such soil-denuded lands to add volume to floods.

Another misconception prevails in the minds of many in regard to the possibilities for restoral of the crop value of severely eroded land. At least the writer feels on perfectly safe ground in asserting that land which has lost its surface-soil layer or layers can not so readily be restored to productivity, generally, as commonly has been supposed. Its condition can be improved, to be sure, by incorporation of vegetable matter and by addition of lime, fertilizers, etc. While yields can be increased in this manner as a matter of course, the rejuvenation process is expensive, and after all is done, the original mellow soil, as nature builds it through ages of developing processes, is not reestablished, and it is not at all unlikely that the same treatment on the virgin soil would give better crop response. The writer has come across what was claimed to be adequately rejuvenated and restored eroded soil where examination showed that the supposedly restored soil was merely an overwash from higher-lying areas. The soil can not be easily restored, if it actually can be restored at all, by purely man-building processes. Perhaps, in some instances, a condition of productivity equal to that of the original soil can be brought about, but that accomplishment alone would not represent the result referred to.

In this connection, it may be of interest to speculate a moment about the rate of soil building. The quantitative results obtained by the Missouri Experiment Station show that soil is removed from the Shelby loam used continuously for corn at the rate of a 7-inch layer in about 49 years, whereas, about 2,320 years are required to remove the same depth of surface material from bluegrass sod. Since a good sod of bluegrass probably represents a very close approximation of the ground conditions under which nature builds grassland soils in the humid climate of the Shelby soil region, it seems reasonable to assume that corn farming as practiced in central and northern Missouri and southern Iowa is causing the loss in 1 year of a layer of soil which nature takes something over 330 years, at least, to build.

Looking further into the significance of natural soil conditions in relation to runoff water, a single illustration will suffice, *viz.*, the loss of water from burned and unburned areas of woodland[9] in the Red Plains of Oklahoma. The burned plat lay immediately alongside the unburned plat, the soil, slope, and vegetation being identical insofar as it is possible to find on two plats of ground. The bulk of forest litter covering one area was burned off, while the other plat was left

[9]Unpublished data obtained by S. W. Phillips and Ira T. Goddard at the Soil Erosion and Moisture Conservation Experiment Station, Guthrie, Okla.

precisely as nature constructed it. From both plats all the runoff and washoff were collected and measured during May, 1930. This was the first heavy rainy period following the installation of the experimental tracts. The runoff from the unburned plat was at the rate of 250 gallons per acre, while the corresponding loss from the burned plat was at the rate of 27,600 gallons per acre. Most of the water fell during one continuous rain.

There was no erosion from the unburned plat, but a moderate amount of soil material was washed off the burned plat. Since the water-holding capacity of the forest-litter was found to be 16.6 tons per acre, it is evident that the altered condition caused a water loss in excess of the normal runoff, plus the water-holding capacity of the forest litter, amounting to approximately 90 tons to the acre.

This shows that forest litter exercises an effect on the water-holding capacity of an area of this type which is much greater than the mere capacity of the litter itself to absorb water. In other words, it seems unquestionably apparent that the moderate erosion on the disturbed plat caused a clogging of the pore spaces of the soil by infiltration of fine soil particles. This conclusion conforms with the recent investigations of Lowdermilk (5).

Accordingly, when forest litter or leaf mold is burned, and probably also when grass is removed, soil stabilizers of marked potency are thereby destroyed—materials which function to send clear or relatively clear water into the normal soil pore spaces, thus to keep them open and capable of carrying down and disposing of a far greater proportion of the rainfall than would be possible under opposite conditions.

When the ground is plowed, again the normal condition of naturally established soil structure is rudely disorganized. Following this, erosion gradually sweeping off the humus layer, upsets the natural conditions of the soil by removal of the more or less sponge-like, absorptive surface material, as previously pointed out.

LOSS OF ORGANIC MATTER AND OTHER CONSTITUENTS

Taking the results of analyses of a few samples representative of important eroded and uneroded cultivated, virgin-prairie, virgin-forest, overgrazed, and moderately grazed soils, marked losses of organic matter have been found in all of the samples wherever serious erosion has taken place, as noted below.

Carrington loam (a dark-colored glacial soil) under virgin forest in southeastern Minnesota was found to contain 23.7% of organic matter in the surface 1½ inches (below the leaf mold) and 8% in the

layer beneath, down to 9 inches; as compared with contents of 3.7% and 0.08%, respectively, in the corresponding depth sections of severely eroded,[10] cultivated land of an adjacent slope, where the soil originally was like that in the timber. The contents of nitrogen were 1.15 and 0.39%, respectively, in the same sections for the forested area and 0.19 and 0.08%, respectively, for the eroded area.

Shelby loam of a forested area in northern Missouri contained 5.1% of organic matter and 0.22% of nitrogen in the surface soil, while the corresponding amounts of these constituents in an adjacent seriously eroded cornfield of the same original type and slope were 0.16 and 0.08%, respectively.

Hays silt loam (a dark soil underlain by limestone) in virgin prairie of western Kansas carried 4.1% organic matter in the soil as against 0.6% in the surface material of an adjoining field where approximately 3 feet of soil and subsoil had been washed off down to within a few inches of bedrock. Approximately 100 acres of the 140 acres in this farm had been eroded to the useless condition represented by the eroded sample.

Gravelly sandy loam occupying a heavily grazed mountain slope in the sheep range country of southern Utah contained 1.4% of organic matter in bush-protected ground, as against 0.4% on soil of the same type which was deeply eroded by a heavy summer rainfall the day before the samples were collected.

A sample of deep black loam taken from a virgin coniferous forest in the Sacramento mountains of New Mexico was found to have 14.6% of organic matter in the surface 14 inches as against 4.5% in the surface 8 inches of a nearby soil which, though originally the same, had been severely eroded following a fire which, 5 years previously, had completely destroyed the forest.

The surface soil from an extensive type of Arizona range land completely protected from grazing by fencing contained 6.7% of organic matter as against 1.6% from the same depth of the same soil type outside the fence which had been severely eroded following excessive grazing.

Cecil sandy loam (a granite-derived soil) from virgin forest in the Piedmont of North Carolina contained 1.6% of organic matter in

[10]The samples referred to in these comparisons between virgin (or partly virgin) and eroded soil conditions do not represent precisely corresponding horizons, since the upper horizon (or horizons) in case of the eroded soils has been swept away in part or entirely; but they do in a measure represent corresponding depth sections, measuring from the surface. The surface soil of the eroded areas, however, was taken to the depth of the more highly humus-charged layers, thus corresponding in the agricultural sense with the surface soil of the virgin (or partly virgin) samples.

TABLE 1.—*Chemical analyses of uneroded soils.**

Soil type	Location	No.	Condition	Depth, inches	Organic matter, %	N, %
Carrington gravelly loam	Minn.	86	Forested: mold below litter	0–1	23.7	1.15
Carrington gravelly loam	Minn.	87	Forested: black loam	1½–9	8.0	0.39
Carrington gravelly loam	Minn.	88	Forested: brown loam	9–30	4.7	0.16
Carrington loam	Minn.	92	Grass: dark loam	0–4	5.0	0.21
Palouse silt loam	Whitman Co., Wash., lower slope	101	Cultivated:† dark silt loam	0–16	3.4¶	0.18
Shelby loam	4½ miles N. W. Ravenwood, Mo.	80	Cultivated:‡ dark loam	0–4	3.5	0.17
Shelby loam	5 miles E. Maryville, Mo.	81	Forested: dark loam, below mold	0–10	5.1	0.22
Boone l. f. s.	Jackson Co., Wis.	121	Forested: brown to yellow brown l.f.s.	0–10	2.3¶	—
Hays silt loam	Rooks Co., Kans.	50	Virgin grass: dark silt loam	0–6	4.1	—
Gravelly sandy loam	6 miles S. E. Panguitch, Utah	25	Grazed: 50% slope, brown gravelly sandy loam	0–10	1.4	—
Mountain loam	Sacramento Mts., N. M.	174	Forested: 50% slope, black loam	0–14	14.6	—
Mountain gravelly loam	Santa Rita Range Res., Ariz., lower slope	85	60% grass cover: overgrazed and eroded, now protected: brown gravelly loam	0–2	2.6¶	—
Gravelly sandy clay loam	5 miles E. Roosevelt, Ariz.	36	Red-brown sandy clay loam, several years protected	0–1½	2.0	—

*Analyses by Bureau of Chemistry and soils.
†60 bushels wheat per acre in year of sampling (1929).
‡Estimated 60 bushels corn per acre year of sampling (1929).
¶Solution loss in H_2O_2.

TABLE 1—*Continued.**

Soil type	Location	No.	Condition	Depth, inches	Organic matter, %	N, %
Gravelly sandy clay loam	5 miles E. Roosevelt, Ariz.	37	12 feet W. No. 36, by coffee-berry	0–2	6.7	—
Cecil silt loam	Near Summerfield, N. C.	A	Virgin forest: yellow brown silt loam	0–7	1.6§	—

*Analyses by Bureau of Chemistry and Soils.
§Analyses by N. C. Agr. Exp. Station.

TABLE 2.—*Chemical analyses of eroded soils.**

Soil type	Location	No.	Condition	Depth, inches	Organic matter, %	N, %
Carrington gravelly loam	300 feet E. Nos. 86–88	89	Cultivated: brown loam	0–3	3.7	0.19
Carrington gravelly loam	300 feet E. Nos. 86–88	90	Cultivated: yellow loam	3–9	1.8	0.08
Carrington loam	12 feet S. No. 92	91	Cultivated:† brown clay loam	0–8	2.7	0.08
Palouse silt loam	Upper slope, above No. 101	103	Cultivated:‡ brown silt loam	0–5	1.4¶¶	0.10
Shelby loam	300 feet E. No. 80	79	Cultivated:§ yellow brown clay loam	0–4	0.9	0.04
Shelby loam	200 yards E. No. 81, brown clay	82	Cultivated:¶ turned out	0–5	1.6	0.08
Boone l.f.s.	12 feet W. No. 121	120	Cultivated:‖ yellow l. f. s.	0–10	0.6¶¶	—
Hays silt loam	200 yards S.E. No. 50	—	Cultivated:** cream colored clay loam	0–6	0.6	—

*Analyses by Bureau of Chemistry and Soils.
†Approximately 40 inches of soil lost by erosion.
‡0 to 11 bushels wheat per acre.
§Estimated 4 bushels of corn per acre, year of sampling (1929).
¶In corn year before (1928).
‖About 2 feet of soil washed off; corn 1929 total failure.
**2 to 3 feet washed off; limestone fragments at surface; Grain sorghum failed 1929.
¶¶Solution loss in H_2O_2.

TABLE 2.—*Continued.**

Soil type	Location	No.	Condition	Depth, inches	Organic matter, %	N, %
Gravelly sandy loam	6 feet from No. 25	26	Light brown*** gravelly sandy loam	0–10	0.4	—
Mountain loam	Opposite side creek from 174	173	50% slope,†† burned: loam	0–8	4.5	—
Mountain gravelly loam	Near No. 85, more eroded, little grass	84	Severely over-grazed and e-roded: red gravelly clay loam	0–2	1.7¶¶	—
Gravelly sandy clay loam	Not protect-ed near plats Nos. 36 and 37	34	Grazed: prac-tically bare	0–1½	1.4	—
Gravelly sandy clay loam	12 feet N. No. 34, not pro-tected	35	Grazed: prac-tically bare	0–2	1.7	—
Cecil silt loam	200 feet E. of A	B	Sed. growth,§§ pine, red clay	0–7	1.0‡‡	

*Analyses by Bureau of Chemistry and Soils.
***Subsoil of No. 25, 10 inches of soil having been washed off by downpour of preceding day (Aug. 15, 1928). No. 25 under protection of clump of white sage; No. 26 in open.
††Sample collected spring of 1930; forest destroyed by fire 1924.
‡‡Analyses by N. C. Agr. Exp. Station.
§§Cultivated, turned out and grown up to 15-year-old pines.
¶¶Solution loss in H_2O_2.

TABLE 3.—*Mechanical analyses of eroded and uneroded soils.**

Uneroded							
Soil No.	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
	%	%	%	%	%	%	%
86	—	—	—	—	—	—	—
87	2.4	7.1	7.4	11.5	4.9	39.8	26.9
88	1.9	6.2	6.3	10.0	4.6	44.5	26.3
92	3.2	7.3	9.5	16.2	10.0	26.5	27.1
101	0.0	0.1	0.1	0.6	4.5	67.3	27.3
80	0.1	0.1	0.2	0.4	0.9	59.4	39.0
81	0.3	1.7	2.5	3.5	3.1	63.0	25.9
121	0.7	21.1	30.0	31.5	3.9	4.1	8.8
25	11.4	13.5	12.5	25.7	10.3	14.0	12.6
85	8.9	14.4	8.2	12.2	7.5	19.5	29.2
36	14.1	12.7	8.7	12.3	7.3	23.3	21.5
37	12.8	13.7	9.0	10.9	5.7	22.8	24.9

*Analyses by Bureau of Chemistry and Soils.

TABLE 3—*Continued.**

Soil No.	Eroded Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
	%	%	%	%	%	%	%
89	4.3	10.3	8.9	12.9	5.3	36.3	22.0
90	25.3	22.6	10.8	8.7	3.8	11.1	17.6
—	—	—	—	—	—	—	—
91	3.5	8.0	8.4	14.4	10.0	24.3	31.4
103	0.0	0.0	0.1	0.6	5.0	62.6	31.5
79	0.7	1.4	2.1	3.9	3.8	35.5	52.5
82	0.6	1.8	2.7	3.6	3.8	45.7	41.9
120	0.4	11.5	30.2	37.6	2.7	11.5	6.2
26	14.7	16.5	13.5	23.0	8.3	14.9	9.2
84	10.2	13.8	6.8	12.0	7.4	25.6	24.2
34	10.3	12.5	10.0	13.2	10.0	30.2	13.9
35	9.2	11.7	8.1	10.7	9.2	40.1	11.0

*Analyses by Bureau of Chemistry and Soils.

the surface 6 inches as against 1% in the same depth of material collected from Cecil clay loam immediately outside the forest, the latter representing formerly cultivated Cecil sandy loam which had lost its surface soil by erosion and then had been abandoned.

Determinations were made of three sets of samples from these extensive soil types, that is, three each from eroded and corresponding uneroded areas, in order to get some idea as to the relative rate of phosphorous losses. The results were as follows: 0.38, 0.14, and 0.13% of phosphoric acid, respectively, in the uneroded samples; and 0.35, 0.05, and 0.06%, respectively, in the eroded samples. These determinations are too few, of course, to use as indicating any definite trend in connection with the phosphorous cycle, but the results are given for what they are worth. The fact that the average content of phosphorous in the surface soil of 80 samples collected from nearly as many important types of farm land in 27 states is 0.162% P_2O_5 as against 0.137% in the corresponding subsoil samples is of much more significance in this connection, since the surface soil has been largely or entirely removed from numerous abandoned areas of formerly cultivated land representing many of the types analyzed, and is being slowly removed from perhaps 75% of all the uplands now in cultivation throughout the nation.

The number of factors affecting processes of erosion is indeed large. For example, the matter of finding soil sufficiently uniform for the purposes of large-plat experimental work at the soil erosion and moisture conservation experiment stations is a most difficult one. It is even difficult in some localities to find satisfactory duplicates for small plats, especially where formerly cropped land is made use of.

TABLE 4.—*Analyses of products of erosion.**

Soil type	Location	No.	Condition	Depth, inches	Mechanical composition						Organic matter %
					Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %	
Gila fine sandy loam	2 miles S. Elmdorf, N. M	169	Overdeposit by 1929 Rio Grande flood: pale yellow loose fine sand	0–10	0.5	5.9	57.4	25.2	6.3	4.6	0.2
Gila fine sandy loam	2 miles S. Elmdorf, N. M.	170	Original soil: reddish brown silty clay	10–24	0.1	0.1	0.4	1.4	44.1	53.8	2.1
Gila clay	1¼ miles S. Val Verde, N. M.	171	Overdeposit by 1929 Rio Grande flood: reddish brown clay	0–12	0.0	0.0	0.0	0.1	7.9	92.0	2.5
Gila clay	1¼ miles S. Val Verde, N. M.	172	Original soil: dark brown heavy fine sandy loam (Anthony)	12–24	0.9		24.8	32.0	14.2	25.1	1.6

*Analyses by Bureau of Chemistry and soils.

Besides the natural variableness in soil depth, erosion has accentuated this feature and introduced other variables in many localities.

In some parts of the country the soil of experiment station plats is, in some instances, getting out of line with the condition of the soil as it existed at the beginning of the experiments because of the large amount of soil removal by rainwash. Indeed, some plats now have a different soil from that on which they had their beginning, the topsoil having been removed completely, either from patches or from the entire area. While losses of organic matter are taking place because of bacterial activities and weathering, this material is also being lost on an enormous scale in the runoff flowing away heavily charged with soil matter. Already some experimental plats have been terraced in order to check the losses; others have been abandoned; and still others may as well be abandoned, it appears, insofar as the results relate to the results obtained in previous years from a very different kind of soil.

SUMMARY

Briefly summarizing this paper, it is to be observed from what has been said that soil erosion is a scientific problem, as well as a business problem, that must be attended to now, not one that we can afford to put off for future generations to solve.

Tables 1 to 4 show some pertinent changes in important eroded and uneroded soils, not only as to organic matter and nitrogen, but as to textural modifications.

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INHERITANCE OF AWNS IN A KOTA X HARD FEDERATION CROSS[1]

George Stewart and B. Ira Judd[2]

Until the last few years awn inheritance in wheat has been regarded as extremely simple, that is, as being dependent on a single factor difference. The awns of the F_1 plants have nearly always been intermediate in length between the awns of the two parents, with the F_2 and F_3 ratios most frequently 3:1 or 1:2:1. Recently, however, it has become apparent that the inheritance of awns is much more complex than the original data indicated. Several workers have found two independent factors and one has found two factors segregating in such a fashion as strongly to suggest linkage.

REVIEW OF LITERATURE

The first genetic study on awnedness inheritance in wheat hybrids was reported in 1905 by Biffen (1)[3] who concluded that "the beardless condition is a dominant, the bearded a recessive character." Other early workers, particularly Tschermak (12) and Spillman (9), obtained similar results in the first generation and in the second generation also, when the awnless and awned plants occurred in a simple Mendelian ratio of 3:1.

Recent studies by Gaines and Singleton (3) show similar segregation, while Percival (7) has also reported F_2 segregation in numerous crosses to approach a 1:2:1 ratio when intermediates occurred.

Saunders (8) questioned the idea that the first generation between an awnless and an awned wheat always is awnless and maintained that the character of awns in the F_1 varied with the wheats used.

Howard and Howard (4) were the first to work with the true awnless wheat. They crossed a fully bearded wheat with one described as being really awnless, a fact they emphasized as important, inasmuch as many of the so-called awnless varieties really have short tip awns. In the F_2, five awn classes were obtained, *viz.*, (a) entirely awnless, (b) short tips, (c) long tips, (d) nearly full bearded, and (e) fully bearded. They grouped all awned and tip-awned classes together as awned which, in comparison with the awnless, gave a 15:1 ratio.

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director, December 1, 1930. Received for publication December 19, 1930.

[2]Formerly Agronomist and Graduate Student, respectively.

[3]Reference by number is to "Literature Cited," p. 464.

These results were explained on a two-factor basis. Four classes bred true, and when the two short-tipped types were crossed, F_2 segregation showed some fully bearded and some awnless plants as well as the intermediate forms. They thus concluded that the awned condition was dominant, which was in opposition to the conclusion of other previous workers.

In similar studies between Kota and Hard Federation, Clark (2) found a somewhat complex condition in the inheritance of awns. He made five classes of awn types in F_2 and arrived at the conclusion that the awnless condition was dominant, since the F_1 (class 2) approached more nearly the awnless than the awned parent and also that two genetic factors could not entirely account for the F_2 and the F_3 breeding behavior.

Nilsson-Ehle (6) obtained by mutation true-breeding forms of awnless, half-awned, and awned wheats. Awnless forms were partly dominant to half-awned and to awned, and half-awned forms to awned. He explained his results on the basis of multiple allelomorphs for half-awned and fully awned plants arising by complex mutation from the awnless plants.

A study in rice has been recently reported by Jones (5) who found evidence of two independently inherited factors for awnedness. In a cross between a fully awned variety and an awnless one, the F_1 was intermediate. He took his data from the F_2 plants and grew some F_3 progenies. He concluded that either of the two factors alone produced an intermediate condition and that the two together produced fully developed awns. He was unable to separate his two intermediate classes.

Stewart (10) reported a strong indication of linkage between two factors for awnedness in a cross between pure lines of Federation and Sevier wheats. A pure line of each parental variety and three F_2 families were used in the study. In two of the families, kernels from all of the F_2 plants were sown for F_3 progeny rows. In the other case, 74 F_3 families were grown, the F_2 plants from which these came being selected at random so far as awns were concerned. There were four true-breeding classes, *viz.*, (a) fully awned, similar to the Sevier parent; (b) awnless, similar to the Federation parent; and (c) and (d) intermediate classes. The true-breeding parental forms were regularly much more numerous than the true-breeding intermediate forms. The F_2 genotypes as classified by the F_3 breeding behavior rather highly substantiated the presence of two factors for awns, both in the same chromosome, with crossing over to the extent of about 35%.

In other crosses Stewart (11) found evidence which indicated that the above theory was at least approximately correct. From these latter studies it is evident that each of the two factors when present separately produces a different, but somewhat equal major effect. The separate effects of the two factors could be identified not only in the true-breeding F_3 progenies but also in the segregating ones.

DESCRIPTION OF THE PARENTS

The parents used, Hard Federation and Kota, are grown only to a limited extent under irrigation in Utah and as yet neither is very well known in this section. Both are valuable varieties in other regions, however, where they are adapted.

HARD FEDERATION

Hard Federation is a variety of white spring wheat which has proved very resistant to drought. It was developed about 1908 by J. T. Pridham, at Cowra Experiment Station in New South Wales, Australia, by selection from Federation. It was introduced into the United States in 1915 and was first tested at the experiment stations at Moro, Oregon, and Chico, California. From these two stations seed was first distributed to farmers.

Hard Federation has awnless, oblong spikes; glabrous, brown glumes; and short, hard, white kernels. It is an early spring wheat with strong stems and small leaves, which twist or curl. This latter habit is thought to decrease transpiration, and Clark (2) states that it is undoubtedly heritable.

Hard Federation has proved to be a high-yielding variety of spring wheat grown under dry-farm conditions at Moro, Oregon. It also does well on some soils of California. In the Pacific Coast and northern intermountain states it often outyields Marquis from 5 to 10 bushels an acre.

KOTA

Kota is a variety of hard red spring wheat which is resistant to black stem rust. The original seed of this variety was obtained from Russia by H. L. Bolley, of the North Dakota Experiment Station, in 1903.

Kota has awned, fusiform spikes; glabrous, white glumes; and mid-long, hard, red kernels. It is a midtall, midseason, spring wheat which has weak to midstrong stems.

The acre yields of Kota have averaged considerably higher in North and South Dakota during the past few years than those of

Marquis, the standard variety of hard red spring wheat, as reported by Clark (2). Kota has also produced good yields in the northeastern parts of Montana and Wyoming. It has proved somewhat resistant to drought, as well as distinctly resistant to black stem rust, in the northern Great Plains area. In the more humid sections of the spring wheat region Kota is not well adapted.

METHODS OF PROCEDURE

The cross between Hard Federation and Kota was made in the spring of 1925 primarily to study the inheritance of awns. Four families were used up to the F_2 generation, but at planting time, in 1928, all but two were discarded.

The F_1 kernels were sown in rows 2 feet apart, with the kernels about a foot and a half apart in the rows. At maturity the heads were harvested and the grain saved for seeding the next season. The kernels from the F_1 plants were sown the next season in rows 1 foot apart with plants 3 or 4 inches apart in the row. Data on the awns of each F_2 plant were taken at the time of harvest.

In the beginning the plants were classified into five classes according to awns, *viz.*, awn class 0 (awnless); awn class 1 (short awn tips); awn class 2 (short awns on the upper half of the spike); awn class 3 (short-tip awns in lower half of spike and part length awns in upper half); and awn class 4 (fully awned). A notation was also made as to the color of the grain and color of the glumes. A head from each plant was threshed to get grain color, and the threshed kernels were placed in an envelope which was marked with the pedigree number and saved until the following year when the kernels from each F_2 plant were seeded in a F_3 progeny row. There was, therefore, an F_3 progeny of 20 to 40 plants from every F_2 plant, 323 in one family and 316 in the other.

It was from the F_3 progeny rows that the data here reported were obtained, each progeny being regarded as denoting the true genotype of F_2 plant from which it was descended. The data on the F_3 progeny plants were taken as soon after heading as the awns were fully developed.

The first thing done in collecting the field data on the F_3 progeny rows was to go through the rows and mark those which appeared to be breeding true for one of the awn types and then go through very carefully a second or third time, if necessary, to make sure they were true-breeding. After this was done the writers went through the rows which were segregating and made a count of the number of plants of each type found, while a helper tallied these.

This was done by getting astride the row and gathering the heads of each plant in a bunch and calling off the awn class to which it belonged. In places where the plants were very thick and the culms more or less interwoven, it was necessary to begin at the ground grasping all the culms of the plant together and following these up to the spikes.

FIG. 1.—Spikes from an F_3 progeny which is true-breeding for awn class 1. The lemmas carry beaks and represent the same range in this respect as the awnless parent, Hard Federation. (Cross 32g, Hard Federation x Kota.)

EXPERIMENTAL RESULTS

It was at first attempted to divide the awns into five classes, in keeping with Clark's (2) suggestions, who thought he found five true-breeding awn classes. Careful checking of F_3 progenies and comparison with the parents showed only four true-breeding classes. Hard Federation ranged from entirely awnless to short beaks. Progenies with a similar range were classified as belonging to awn class 1. The F_2 awn class 0 thereby became part of awn class 1.

In family 32G there were 323 F_3 progenies (Fig. 1) each from a single F_2 plant. The plants of each F_3 family were classified according to awns. A summary of the data follows:

No. of F_3 families breeding true for		No. of F_3 families segregating for	
Awns 1	18	Awns 1, 2	37
Awns 2	21	Awns 1, 2, 3	48
Awns 3	20	Awns 1, 2, 3, 4	78
Awns 4	19	Awns 2, 3, 4	43
		Awns 3, 4	39

FIG. 2.—Spikes of an F_3 progeny which is true-breeding for awn class 2. The awn development in this class is markedly greater than that of the Hard Federation parent and resembles closely the F_1 condition obtained. (Cross 32g, Hard Federation x Kota.)

In family 33F an F_3 progeny of every F_2 plant was likewise grown. The plants in each of the 316 rows were classified and the data summarized by families as follows:

No. of F_3 families breeding true for		No. of F_3 families segregating for	
Awns 1	21	Awns 1, 2	32
Awns 2	17	Awns 1, 2, 3	32
Awns 3	16	Awns 1, 2, 3, 4	81
Awns 4	23	Awns 2, 3, 4	47
		Awns 3, 4	48

An examination of the summaries of awn behavior shows that there occurred nine genotypes of plants according to awn-breeding be-

havior in F_3. Four of these bred true and five segregated each in a distinct manner.

Let us designate full awns, such as occur in the Kota parent, by AATT (awn class 4); long apical awns, but short lateral awns (awn class 3) by AAtt; well developed tip awns (awn class 2) by aaTT (Fig. 2); and very short tip awns and awnless beaks by aatt (awn

FIG. 3.—Spikes of an F_3 progeny which is true-breeding for awn class 4. The awn development in this class is similar to that of the fully awned parent, Kota. (Cross 32g, Hard Federation x Kota.)

class 1). Awn class 1, as here determined, has the same range as the awnless parent, Hard Federation.

The following F_2 zygote genotypes as far as awns are concerned are expected:

(1) AATT
(2) AATt
(3) AaTT
(4) AaTt
(5) AAtt
(6) Aatt
(7) aaTt
(8) aaTT
(9) aatt

The expected breeding nature of the nine zygotypes is indicated here:

(1) Breed true for awns 4
(2) Segregate for awns 3, 4
(3) Segregate for awns 2, 3, 4
(4) Segregate for awns 1, 2, 3, 4
(5) Breed true for awns 3
(6) Segregate for awns 1, 2, 3

(7) Segregate for awns 1, 2
(8) Breed true for awns 2
(9) Breed true for awns 1

Of the nine sorts of genotypes, 1, 5, 8, and 9 are the true-breeding forms (Fig. 3) for awn classes 4, 3, 2, and 1, respectively. Genotypes 2 and 3 are each homozygous for one dominant factor and heterozygous for the other, 2 being heterozygous for Tt and 3 for Aa. Genotypes 6 and 7 differ only in that 6 is homozygous recessive for tt and heterozygous for Aa, whereas 7 is homozygous recessive for aa and heterozygous for Tt.

On the basis of total F_3 families, the ratios of families that bred true for awns in various ways suggest a two-factor difference. A strictly independent segregation would give approximately equal numbers in each of the four classes that bred true. This was found in both families studied. There was found a ratio that approximates a 1:2:2:4:1:2:1:2:1 ratio for independent segregation, or a 9:3:3:1 ratio taking the nine genotypes, which indicates a two-factor difference. While there is a much closer approximation to this in family 32G than in family 33F, as indicated by the goodness of fit study, both values are such as to be highly corroborative of the two-factor hypothesis.

TABLE 1.—*Calculated (C) and observed (O) numbers of F_2 genotypes as determined by the F_3 breeding behavior.**

Genotype	O	C	O–C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
AATT	19	20.1875	—1.1875	1.4101	0.0698
AATt	39	40.375	—1.375	1.8806	0.0465
AaTT	43	40.375	2.625	6.8906	0.1706
AaTt	78	80.75	—2.75	7.5625	0.0937
AAtt	20	20.1875	—0.1875	0.0352	0.0012
Aatt	37	40.375	—3.375	11.3906	0.2821
aaTt	48	40.375	7.625	58.1416	1.4403
aaTT	21	20.1875	0.8125	0.6602	0.0327
aatt	19	20.1875	—1.1875	1.4101	0.0698
Total.....	323	323	P =	.9714	$X^2 = 2.2067$

*Family 32G; grown in 1928 at Logan, Utah.

In Table 1 the closeness of fit to the calculated expectancy is given for family 32G. P = .9714, which is an extremely good fit, shows that in 97 cases of 100 worse fit might be expected due to chance alone. In Table 2, the closeness of fit for family 33F is shown to be .4526 which, though not nearly so good a fit as found in family 32G, still indicates a good one.

As stated before, both these families approximate a 1:2:2:4:1:2:2:1 ratio, which is what is expected for strictly independent segregation. It may be safely concluded, therefore, that the F_2 genotypes as

classified by the F_3 breeding behavior rather highly substantiate the presence of two factors for awns, independently inherited.

TABLE 2.—*Calculated (C) and observed (O) numbers of plants in each awn group of F_2 genotypes as determined by the F_3 breeding behavior.**

Genotype	O	C	O–C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
AATT	23	19.75	3.25	10.5625	0.5348
AATt	48	39.50	8.50	72.2500	1.8291
AaTT	47	39.50	7.50	56.2500	1.4240
AaTt	81	79.00	2.00	4.0000	0.0506
AAtt	16	19.75	—3.75	13.0625	0.6669
Aatt	32	39.50	—7.50	56.2500	1.4240
aaTt	32	39.50	—7.50	56.2500	1.4240
aaTT	17	19.75	—2.75	7.5525	0.3824
aatt	21	19.75	1.25	1.5625	0.0790
Total....	316	316	P=	0.4526	$X^2=7.8148$

*Family 33F; grown in 1928 at Logan, Utah.

One worker who had used these varieties questioned that there were really true-breeding rows of awn class 3, or in awn class 4 in the

FIG. 4.—Spikes of an F_3 progeny which is true-breeding for awn class 3. As in awn class 1 group the awn development is greater than that of one parent (Hard Federation) and less than that of the other (Kota). As compared with awn class 2, the awns in awn class 3 are longer at the apex and show distinctly as awn points in the lower part of the spikes. The F_3, the F_4, and the F_5 generations were alike in these awn class 3 true-breeding progenies. (Cross 32g, Hard Federation x Kota.)

grouping used by Clark (2). In order to make certain of this, the data were not published until F_4 and F_5 rows were grown, establishing beyond all doubt that the rows were really true-breeding. The

photographs (Fig. 4) of the awn classes were all made from F_4 rows, the parents of which were progenies classified in F_3 as being true-breeding. Another generation (F_5) was grown and checked against the photographs. Since the F_3, the F_4, and the F_5 generations behaved alike without any evidence of segregation, it is thought that the true-breeding condition of this class of awns, as well as that of the others, is fully established.

SUMMARY

This cross was made to study awn inheritance and to discover, if possible, the number of factors involved. The parents used in the cross were Hard Federation, an awnless variety, and Kota, a fully awned wheat.

In F_3, all the F_2 genotypes were tested by the breeding behavior of F_3 families, each from a single F_2 plant. Four true-breeding classes were found and five which segregated each in a distinct manner.

When the observed proportions of each of these 9 genotypes were studied by the closeness-of-fit method, the two P's were 0.97 and 0.45, both good fits. It seems reasonable to conclude that there is a two-factor difference for awns, independently inherited. The classes were clear-cut and definite when determined by the F_3 breeding behavior, and as carefully checked in the F_4 and the F_5 generations.

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SUSCEPTIBILITY OF MARKTON AND OTHER VARIETIES OF OATS TO COVERED SMUT (*USTILAGO LEVIS*)[1]

D. C. SMITH AND E. N. BRESSMAN[2]

Markton oats, C. I. 2053, has been reported as immune to covered smut (*Ustilago levis*) by Stanton, *et al.*,[3] and others. The trials reported herein, however, indicate that Markton is susceptible to certain collections of covered smut, and that Black Mesdag, C. I. 1765, is more resistant to these collections.

The Markton seed used in these tests was originally obtained from Moro, Oregon, where the variety was developed. Since that time it has been grown in the small grain nursery at Corvallis. In this paper the normal seeds are designated as unhulled and those with hulls removed as hulled. Carefully selected seed typical of the variety was used in these trials. The plantings were made in the field at Corvallis, Oregon, in 1929 and 1930. All of the plants observed were typical of the variety. In fact Markton shows little variation and is practically a pure line, although some differing selections have been made.

Ordinarily, the percentage of smut in oat fields in Oregon is not high. The large amount of smut present in some fields, however, attracted attention, and so smut collections were made. In the fields where the collections used in these tests were obtained, the smut infection was as high as 65% by actual count. The collections of smut are listed and described in Table 1. All of the collections were designated as *U. levis* and all except collections Nos. 1 and 7 were typical of this species. In the latter collections, however, several of the heads and spores approached *U. avenae* in appearance and the collections may have been mixtures of both species.

In 1928, three smut collections were made. These are numbered one to three in Table 1. Seed of Markton was hulled and heavily coated with equal amounts of spores of these collections three weeks previous to planting. The grain was sown in rows 8 feet long on April 24, 1929. On June 19, when the plants were 5 inches high, half of each row was cut back with scissors to retard the growth of the plants. All of the smut observed in 1929 was found in the cut half of the row, indicating that the resistance of the plant was lowered or

[1]Contribution from the Farm Crops Department, Oregon Agricultural Experiment Station, Corvallis, Ore. Published with the approval of the Director as Technical Paper No. 140. Received for publication December 23, 1930.

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[3]STANTON, T. R., STEPHENS, D. E., and GAINES, E. F. Markton, an oat variety immune from covered smut. U. S. D. A. Circ. 324. 1924.

that the fungus was given an opportunity to keep pace with the growth of the plant. In 1930, the plants were not retarded because they did not make sufficient growth. From the smutted heads inoculum was saved for the 1930 plantings. The results given in Table 2 were obtained by using the smut of the 1928 collections for inoculum.

TABLE 1.—*Collections of covered smut (Ustilago levis) of oats used in these trials.*

Collection No.	Variety grown on	Smut in field, %	Source	Year collected
1*	Silvermine	10	Enterprise, Ore.	1928
2	Climax	45	Corvallis, Ore.	1928
3	Climax	12	Powell Butte, Ore.	1928
4	Markton	8	Bend, Ore.	1929
5	Victory	8	Bend, Ore.	1929
6	Grey Winter	5	Corvallis, Ore.	1929
7*	Grey Winter	3	Corvallis, Ore.	1929

*Variable in appearance, possibly mixed with *U. avenae*.

In 1929, the hulled Markton seed, inoculated with collection 1, produced 60 heads of grain, 1 of which was smutted, or 1.7%. Seed inoculated with collection 2 produced 47 heads, 3 of which were smutted, or 6.4%. Seed inoculated with smut collection 3 produced 58 heads, 6 of which were smutted, or 10.3%. A check row with 65 heads from hulled seed gave no smut. In 1930, a much higher infection was obtained, using the same inoculum held over from 1928. This is evident by comparing column 3 with column 6 in Table 2. There was 17.7% infection in 1930 for an average of all collections.

TABLE 2.—*Percentage of covered smut produced on hulled Markton oats by inoculating the seed with various collections of smut, Corvallis, Oregon, 1929 and 1930.*

Smut collection	1929			1930		
	Smutted heads	Total heads	Smut, %	Smutted heads	Total heads	Smut, %
1	1	60	1.7	3	33	9.1
2	3	47	6.4	17	79	21.5
3	6	58	10.3	7	31	22.5
Check (not smutted)	0	65	0.0	—	—	—

Table 3 shows the results of coating the seed of four varieties of oats with seven different collections of smut. All inoculum used in this trial was obtained from the crop of 1929. That of collections 1, 2, and 3 was grown on Markton in 1929. The increased percentage of infection as shown in Table 3 may be due to the screening out of strains of smut. The small number of heads produced in 8-foot rows was due to extreme drouth.

In 1930, a comparison was made between hulled and unhulled seed

TABLE 3.—*Total and smutted heads of four varieties of oats inoculated with various collections of covered smut, Corvallis, Oregon, 1930.*

Smut collection No.	Markton				Black Mesdag				Eclipse				Victory			
	Unhulled		Hulled		Unhulled		Hulled		Unhulled		Hulled		Unhulled		Hulled	
	Total	Smut	Total	Smut	Total	Smut	Total	Smut	Total	Smut	Total	Smut	Total	Smut	Total	Smut
1	28	2	9	5	16	0	21	0	10	6	0	0	15	1	10	5
2	47	2	12	6	39	0	18	0	1	0	1	1	36	2	18	3
3	26	3	5	3	29	0	7	0	3	0	2	1	21	2	15	7
4	49	1	13	2	16	0	19	0	13	3	1	1	23	4	14	5
5	38	4	8	1	88	0	34	0	18	0	3	3	20	2	7	7
6	34	1	14	4	30	0	19	2	12	0	2	1	37	2	7	4
7	20	4	0	0	29	1	14	1	2	0	2	0	41	2	9	1
Total..........	242	17	61	21	247	1	132	3	59	9	11	7	193	15	80	32

(Table 4). Stanton, *et al.*,[4] Bayles and Coffman,[5] and others have shown that hulling increases the percentage of smut infection. The literature on the subject is reviewed in the first-mentioned report.

TABLE 4.—*Summary of the total number of heads smutted in four varieties of oats by seven collections of covered smut and the increase in percentage of smut due to hulling the seed, Corvallis, Oregon, 1930.*

Variety	Unhulled		Hulled		Unhulled smutted, %	Hulled smutted, %	Increase from hulling, %
	Total	Smut	Total	Smut			
Markton	242	17	61	21	7.02	34.42	390
Black Mesdag	247	1	132	3	0.04	2.27	5,575
Eclipse	59	9	11	7	15.25	63.6	246
Victory	193	15	80	32	7.77	40.0	415
Total or average	741	42	284	63	7.5	35.07	367

As an average of all of the varieties tested in these trials, there was a 367% increase of infection when hulled seed was used. The smut infection due to hulling, however, was not the same in all varieties. In Black Mesdag the percentage was increased several times, while in Eclipse there was the least increase. Markton and Victory were intermediate in this respect compared to Black Mesdag and Eclipse. Hulling decreased the total number of heads produced in the four varieties by 56%. This decrease is undoubtedly due to unfavorable conditions being more severe on the unprotected kernels.

Eclipse, a side oat selected by an Oregon grower from a locally grown big white variety, gave the highest average smut infection, with 23% for the average of hulled and unhulled kernels. Victory gave 17%, Markton 12%, and Black Mesdag 1% of smut. All seven collections of smut produced smutted grain on Markton and Victory. Collection 7 did not produce smut on Eclipse, but this may be due to the small number of heads produced in this variety. Collections 6 and 7 both smutted Black Mesdag, but only slightly.

The trials show that Black Mesdag is more resistant to these collections of covered smut than Markton. Also, the trials indicate the desirability of testing the resistance of a variety to many collections of an organism before establishing its resistance. Retarding the growth of the plant caused an expression of the disease in the head when no expression was obtained in plants not retarded. This indicates that plants may be infected with smut and possibly reduced in yield and still show no evidence of disease.

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VARIATIONS IN STAND AS SOURCES OF EXPERIMENTAL ERROR IN YIELD TESTS WITH CORN[1]

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The aim of investigators concerned with agronomic plat trials is to eliminate as many sources of error as possible. Variations in stand in test plats of corn are commonly obtained in spite of most careful attention to details of planting, thinning, and cultivation. It is essential to know the effect of such variations in order to obviate, so far as possible, such effect at harvest.

Reduction of stand in varietal trials may result from seed-borne infection with the seedling blight organisms; and also from other uncontrolled sources of error, such as insect or rodent injury, variations in germination, particularly in a dry spring, and accidental destruction of plants during cultivation. Variations in stand in varietal trials may be obviated to a considerable extent by planting thick and later thinning to a uniform stand. Where studies on the effect of seedling blight diseases are being conducted, such a practice is obviously undesirable.

Reduced stand as an important source of error in yield trials was demonstrated by Kiesselbach[3] in studies conducted for two years at the Nebraska Station. He found, in 1914, that the relative grain yields of 3-plant, 2-plant, and 1-plant hills surrounded by hills having a full stand of 3 plants were 100, 82, and 74, respectively. In 1917, the corresponding relative yields were 100, 83, and 50. In 1914, 3-plant hills adjacent to one hill with 2 plants, one hill with 1 plant, one blank hill, and two blank hills, respectively, and otherwise surrounded by a full stand, were increased in yield 3, 5, 13, and 43%, respectively. In 1917, the corresponding increases were 2, 9, 15, and 25%.

Olson[4] found variations in stand closely correlated with yield per acre. In the course of a seed study experiment in which ear rows of

[1]Paper No. 988 of the Journal Series, Minnesota Agricultural Experiment Station, St. Paul, Minn. Received for publication December 22, 1930.

[2]This study was completed while the writers were Assistant Plant Geneticists, Division of Agronomy and Plant Genetics, University of Minnesota. The writers are now Associate Agronomist and Associate Geneticist, Office of Sugar Plants, U. S. Dept. of Agriculture, Ft. Collins, Colorado, and St. Paul, Minnesota, respectively. Acknowledgment is due Dr. H. K. Hayes for help in planning these studies.

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18 hills each were grown from 82 ears, yields from these rows were grouped into classes according to the stand. Classes ranged from an average of 18 plants per row to 51 plants per row, with a resulting corresponding range of from 5.96 to 12.90 pounds dry shelled corn per row of 18 hills. The yield increment paralleled closely the stand increment, indicating practically no effect of competition.

The studies herein reported were made to determine the relative errors which would result from harvesting plats with reduced stands under Minnesota conditions.

EXPERIMENTAL METHODS

The experiment was conducted for two years (1928 and 1929) at University Farm, St. Paul, and at Waseca, Minnesota. A somewhat different plan was followed at the two stations, and the data will be presented in separate tables. For the study with inbred lines at University Farm the yield of single plant hills spaced 1 foot apart in the row was used as the standard of comparison. In all other trials the yield of 3-plant hills surrounded on four sides by 3-plant hills was used.

Selfed lines and single crosses of selfed lines were planted at University Farm in 1928; while in 1929, because of lack of seed, double crosses were substituted for the single crosses. The lines used in the yield trial of selfed lines originated from dent varieties, while those which entered into the crosses came from both dents and flints. Because of limited seed, plats were repeated only once, except in 1929 when a triplicated plat test was used with the double crosses.

The following diagrams are presented to show the plan used for the University Farm trials:

Selfed Lines, University Farm

Row			
a	Single plants	1 foot apart	44 foot row
b*	3-plant hills	3½ feet apart	44 foot row
c	Single plants	1 foot apart	44 foot row
d*	Single plants	1 foot apart	44 foot row
e	Single plants	1 foot apart	44 foot row
f*	Single plants	2 feet apart	44 foot row
g	Single plants	1 foot apart	44 foot row
h*	Single plants	1 foot apart	44 foot row
i	Single plants	1 foot apart	44 foot row
j*	Single plants	3 feet apart	44 foot row
k	Single plants	1 foot apart	44 foot row

*Starred rows were harvested for yield. The block of rows *a* to *k* was systematically repeated once for each strain. Rows *d* and *h* were handled alike and constitute the checks with which rows *b*, *f*, and *j* were compared.

Crosses, University Farm, 1929*

Row	Hills with number of plants											
a	3	3	3	3	3	3	3	3	3	3	3	......17 hills
b	3	3	3	3	3	3	3	3	3	3	3	......17 hills
c	3	3	0	3	0	3	0	3	0	3	0	......17 hills
d	3	3	3	3	3	3	3	3	3	3	3	......17 hills
e	3	3	3	3	3	3	3	3	3	3	3	......17 hills
f	3	3	3	3	3	3	3	3	3	3	3	......17 hills
g	3	3	2	3	2	3	2	3	2	3	2	......17 hills
h	3	3	3	3	3	3	3	3	3	3	3	......17 hills
i	3	3	3	3	3	3	3	3	3	3	3	......17 hills

*The same plan was used in 1928, except that blank hills were alternated with 2-plant hills in row *g*. The rows *a* to *i* were systematically repeated once in 1928, and twice in 1929. The hills were spaced 3½ feet in both directions.

In 1928, the soil was very dry at time of planting. Germination in the crosses was fairly good but poor in the selfed lines. For this reason data obtained on the selfed lines in 1928 were incomplete and are not included in this report. Yields are calculated on a 14% moisture basis for ear corn, the weight having been taken on oven-dried ears.

The experiment at Waseca was conducted in a somewhat different manner. Ten selfed lines and 10 single crosses of Silver King white dent corn were used. Both F_1 crosses and selfed lines were planted 3½ by 3½ feet. Individual hills were harvested within each cross or selfed line, and the average yield of each group of hills subjected to the same type of competition was obtained. The percentage yield was calculated from field weights, corrected to a 14% moisture basis.

The general scheme for planting at Waseca is illustrated by the following diagram:

3	3	3	3	3	3	3	......18 hills
3	0	3	0	3	0	3	......18 hills
3	3	3	3	3	3	3	......18 hills
3	3	3	3	3	3	3	......18 hills
3	3	3	3	3	3	3	......18 hills
3	3	3	3	3	3	3	......18 hills

Each of the 10 selfed lines or F_1 crosses was planted in five-row plats of 18 hills each, as illustrated above. The yields of three-stalk hills in row 4, completely surrounded by three-stalk hills, were used as the standard of comparison.

The 1- and 2-plant comparisons were made the same, except that 1-plant or 2-plant hills, respectively, were substituted for the blank hills. The average from the averages of the 10F_1 crosses, or selfed lines, were used in making the analyses reported here.

TABLE 1.—*Competition in selfed lines, University Farm, 1929.*

Strain No.	Variety	Yield, bushels per acre*	Yield, grams per plant				Relative yield per plant, with 1-plant hills, 1 apart, as 100		
			3-plant hills, 3½ ft. apart	1-plant hills			3-plant hills, 3½ ft. apart	1-plant hills	
				1 ft. apart	2 ft. apart	3 ft. apart		2 ft. apart	3 ft. apart
43	Minn. No. 13	22.7	60.3	73.2	81.5	91.6	82.4	111.3	125.1
44	Minn. No. 13	29.8	79.3	87.2	90.7	119.7	90.9	104.0	137.3
63	N. W. Dent	17.7	47.1	57.1	75.6	70.2	82.5	132.4	122.9
66	N. W. Dent	11.2	29.7	30.0	26.0	34.6	99.0	86.7	115.3
51	Rustler	32.8	87.4	93.3	114.0	121.7	93.7	122.2	130.4
53	Rustler	28.0	74.8	73.5	108.1	134.8	101.8	147.1	183.4
Average							91.7	117.3	135.7
Average not including strain 66							90.3	123.4	139.8

*Yield in bushels per acre taken for 3-plant hills, 3½ feet apart.
P.E. in grams per plant for two-plat test = 5.69; P.E. in per cent for two-plat test = 7.42.

EXPERIMENTAL RESULTS

Yields for the selfed lines at University Farm for 1929 are summarized in Table 1.

The yields of the lines used varied from 11.2 to 32.8 bushels per acre. It was thought probable that the more vigorous-growing selfed lines would show more competition effect than would the less vigorous strains, and the lines were chosen to obtain such variability.

The number of available hills harvested per plat and with only two systematically replicated plats would, of necessity, give large errors. Thus, with a probable error of 5.69 grams per plant, wide deviations might well be expected due to random errors. This precludes the possibility of analyzing small differences. The yields of strain 66 for single plant hills 1, 2, and 3 feet apart are 30.0, 26.0, and 34.6 grams, respectively. About all that can be concluded is that plants of this selfed line do not give as great an increase in yields due to more space for development as is obtained with the higher yielding strains. There is, in general, a greater increase in yield in the better yielding selfed lines due to increased distance between plants than in the lower yielding lines. However, this does not seem to be directly proportional to the yield of the line, for line 53 of Rustler gave the largest increases in yield in response to increased space for development, while lines 44 and 51 yielded most in bushels per acre.

TABLE 2.—*Effect of competition in F_1 crosses at University Farm, St. Paul, average yield, 1928.*

Hills surrounded by 3-plant hills, except as noted	Dent crosses (6)*		Flint crosses (2)*		All crosses (8)*	
	Bushels per acre	% of check	Bushels per acre	% of check	Bushels per acre	% of check
3-plant hills adjacent to one blank hill	46.8	100.0	49.7	133.2	47.5	107.0
3-plant hills between two blank hills	48.4	103.3	55.1	147.6	50.0	112.6
3-plant hills adjacent to one 2-plant hill, blank hills on two corners	46.0	98.4	48.2	129.2	46.6	104.8
3-plant hills surrounded by 3-plant hills (check)	46.8	100.0	37.3	100.0	44.4	100.0
2-plant hills between two blank hills	35.3	75.4	45.2	121.0	37.8	85.0

*Figures in parenthesis indicate number of crosses in test.

P.E. in bushels per acre for 2-plat test = 2.12; P.E. in per cent for 2-plat test = 4.67.

Single plants spaced 1-foot apart yielded more per plant as an average for all strains than plants in 3-plant hills spaced 3½ feet

TABLE 3.—*Effect of competition in double crosses, University Farm, St. Paul, average yield, 1929.*

Hills surrounded by 3-plant hills, except as noted	Dent crosses (2)*		Flint-dent crosses (3)*		Flint crosses (1)*		All crosses (6)	
	Bushels per acre	% of check	Bushels per acre	% of check	Bushels per acre	% of check	Bushels per acre	% of check
3-plant hills adjacent to one blank hill	66.3	112.0	86.9	120.0	78.7	111.6	78.7	116.2
3-plant hills between two blank hills	68.0	114.9	81.6	112.7	78.9	111.9	76.6	113.1
3-plant hills adjacent to one 2-plant hill	64.5	109.0	75.0	103.6	67.6	95.9	70.3	103.8
3-plant hills between two 2-plant hills	64.0	108.1	74.3	102.6	68.4	97.0	69.9	103.2
3-plant hills surrounded by 3-plant hills (check)	59.2	100.0	72.4	100.0	70.5	100.0	67.7	100.0
2-plant hills surrounded by 3-plant hills	47.0	79.4	66.3	91.6	59.1	83.8	58.7	86.7

*Figures in parenthesis indicate number of crosses in test.
P.E. in bushels per acre for 3-plat test = 2.89; P.E. in per cent for 3-plat test = 4.11.

apart, in spite of the fact that there are 16.7% more plants per acre with the 1-foot spacing. It is apparent that there is considerable competition between plants in a 3-plant hill.

The yields for single crosses in 1928 and double crosses in 1929 in bushels per acre for the various methods of test and in percentage of full stand are given in Tables 2 and 3. In Table 4, yields in percentage of the check are grouped into percentage yield classes for each cross for the two years of the experiment.

TABLE 4.—*Yield in percentage of check, University Farm, St. Paul, single crosses 1928, double crosses 1929.*

Type of comparison and year	Percentage yield classes										
	60	70	80	90	100	110	120	130	140	150	160
3-plant hills adjacent to one blank:											
Dent, 1928	–	–	–	1	5	–	–	–	–	–	–
Flint, 1928	–	–	–	–	–	1	–	–	–	–	1
Dent, 1929	–	–	–	–	–	2	–	–	–	–	–
Flint-Dent, 1929	–	–	–	–	–	1	1	1	–	–	–
Flint, 1929	–	–	–	–	–	1	–	–	–	–	–
3-plant hills between two blanks:											
Dent, 1928	–	–	–	2	2	1	1	–	–	–	–
Flint, 1928	–	–	–	–	–	–	–	–	1	–	1
Dent, 1929	–	–	–	–	–	1	1	–	–	–	–
Flint-Dent, 1929	–	–	–	–	–	2	1	–	–	–	–
Flint, 1929	–	–	–	–	–	1	–	–	–	–	–
3-plant hills adjacent to one 2-plant hill, blank hills on two corners:											
Dent, 1928	–	–	1	1	1	3	–	–	–	–	–
Flint, 1928	–	–	–	–	–	1	–	–	–	1	–
3-plant hills adjacent to one 2-plant hill:											
Dent, 1929	–	–	–	–	1	1	–	–	–	–	–
Flint-Dent, 1929	–	–	–	–	1	2	–	–	–	–	–
Flint, 1929	–	–	–	–	1	–	–	–	–	–	–
3-plant hills between two 2-plant hills:											
Dent, 1929	–	–	–	–	1	1	–	–	–	–	–
Flint-Dent, 1929	–	–	–	1	–	2	–	–	–	–	–
Flint, 1929	–	–	–	–	1	–	–	–	–	–	–
2-plant hills between two blank hills:											
Dent, 1928	1	1	3	1	–	–	–	–	–	–	–
Flint, 1928	–	–	–	–	–	1	–	–	–	–	–
2-plant hills surrounded by 3-plant hills:											
Dent, 1929	–	–	2	–	–	–	–	–	–	–	–
Flint-Dent, 1929	–	–	1	–	2	–	–	–	–	–	–
Flint, 1929	–	–	1	–	–	–	–	–	–	–	–

Eight F_1 crosses including six dent and two flint crosses were used in 1928. The yields of 3-plant hills with a blank hill on one side were increased 7.0%, and a blank on two sides resulted in a 12.6% increase. Two plant hills between two blank hills yielded 85.0% as much as the checks. The flint crosses appear to have responded to increased area for development to a much greater extent than did the dent crosses. In fact, the only increase obtained for an average of the six dent crosses was 3.3% with 3-plant hills between two blank hills.

With the greater average yield per acre in 1929 as compared to 1928, there appears to have been more resultant competition effect with dent crosses. The yields in 1929 were increased 9.0, 8.1, 12.0, and 14.9%, respectively, for 3-plant hills adjacent to one 2-plant, two 2-plant, one blank, and two blank hills. The corresponding increases for all crosses were 3.8, 3.2, 16.2, and 13.1%, the results obtained for the flint-dent and flint crosses being for the most part similar to the dents. The reduction in yield for 2-plant hills surrounded by full stand as compared to corresponding 3-plant hills was 13.3% for the dent, flint-dent, and flint crosses combined.

As an average for all crosses in 1929, a blank space surrounded by full stand hills resulted in a net loss of at least 35.2% of the potential yield of a single missing hill. The net loss might be less than this since there was no measure of the effect on corner hills obtained. A 2-plant hill resulted in a corresponding net increase of 1.9%, for while there was a decrease of 13.3% in the yield of the 2-plant hills, this was more than compensated for by the increase in yield for the four hills adjacent to the 2-plant hill. In the case of single-row plats, or three-row plats where the central row is harvested for yield, there would be on this basis a net loss of 5.8% of the yield of one 2-plant hill which was harvested with two adjacent 3-plant hills.

In Table 5 are presented the results obtained at Waseca, Minnesota, with both selfed lines and F_1 crosses. The average yields of the selfed lines during the two years of 1928 and 1929 were 33.7 and 36.3 bushels per acre, respectively. The average yields of the checks in the F_1 crosses were 76.3 and 78.4 bushels per acre in the same years.

For the most part the results obtained for the two years at Waseca were quite similar. Three-plant hills of selfed lines adjacent to two blank hills gave increased yields of only 5.5% due to the benefit of greater room for development. This is not a very marked effect and with wide differences in yield would not be of very great importance. Much greater error is introduced when 1-plant hills are used to estimate yielding ability when a stand of 3-plant hills is used

as the standard of comparison. It seems evident that yield trials with selfed lines should be made on the basis of full stand hills surrounded by full stand hills.

TABLE 5.—*Competition in selfed lines and F_1 crosses at Waseca.*

Type of comparison*	1928		1929		Both years	
	No. of hills	Yield in % of check	No. of hills	Yield in % of check	No. of hills	Yield in % of check
		Selfed Lines				
3-plant hills between two blanks	52	105.5	14	105.6	66	105.5
3-plant hills opposite a blank	50	110.7	15	90.5	65	106.0
3-plant hills with two blanks on corners	33	117.7	6	58.2	39	108.5
3-plant hills between two 1-plant hills	60	107.9	14	91.9	74	104.9
3-plant hills opposite a 1-plant hill	63	98.7	9	111.2	72	100.3
3-plant hills with two 1-plant hills on corners	37	94.0	8	105.7	45	96.1
1-plant hill surrounded by 3-plant hills	66	40.6	13	36.6	79	39.9
		F_1 Crosses				
3-plant hills between two blanks	49	107.6	68	109.9	117	108.9
3-plant hills opposite a blank	31	104.8	47	106.2	78	105.6
3-plant hill with blanks on two corners	24	102.5	45	99.0	69	100.2
3-plant hills between two 1-plant hills	43	102.9	51	105.9	94	104.5
3-plant hills opposite a 1-plant hill	38	108.5	34	98.3	72	103.7
3-plant hills with two 1-plant hills on corners	31	102.6	44	100.1	75	101.1
3-plant hills between two 2-plant hills	28	106.5	48	100.2	76	102.5
3-plant hills opposite a 2-plant hill	43	102.3	34	100.4	77	101.5
3-plant hills with two 2-plant hills on corners	18	97.0	28	103.2	46	100.8
1-plant hill surrounded by 3-plant hills	52	38.4	44	44.0	96	41.0
2-plant hills surrounded by 3-plant hills	45	70.9	42	80.2	87	75.4

*Three-plant hills surrounded by 3-plant hills were used as checks.

When the results with F_1 crosses from both years are considered, very uniform results are obtained. One- and 2-plant hills surrounded by 3-plant hills yielded 41.0% and 75.4% as much as the checks. It seems evident from these data that reliable yield data can be obtained only when 3-plant hills surrounded on four sides by 3-plant hills are harvested. Single blank hills adjacent to 3-plant hills increased the yields of these 3-plant hills by 5.6%, 1-plant hills simi-

larly situated increased yields of adjacent 3-plant hills 3.7%, and 2-stalk hills resulted in an increase of 1.5%. When two blank, two 1-plant, or two 2-plant hills were adjacent to 3-plant hills, with 3-plant hills on the other two sides, the increases were only 8.9, 4.5, and 2.5%, respectively. It seems that 1- or 2-plant hills adjacent to 3-plant hills did not greatly affect the yield of the 3-plant hills under the conditions of these experiments. Blank, 1-plant, and 2-plant hills on the corners of 3-plant hills otherwise surrounded by 3-plant hills did not result in appreciable increases in yield.

Under the conditions of this experiment, the yields of 3-plant hills surrounding single blank, 1-plant, or 2-plant hills, respectively, are increased sufficiently to account for 23, 60, and 85%, respectively, of the yields which would have been obtained if three 3-plant hills had been obtained instead of the blank, 1-plant, or 2-plant hills. The harvesting of 2-plant hills, even when surrounded completely by 3-plant hills, resulted in loss, in the area allotted to that hill, of 15%. One-stalk or blank hills introduce correspondingly greater errors. A smaller error is introduced in harvesting 3-plant hills with blank hills on two sides than in harvesting 2-plant hills surrounded by a perfect stand.

DISCUSSION

It is evident from the data presented that there is considerable competition in selfed lines due to variations in stand. Studies intended to demonstrate the effect of disease-producing organisms on the yields of corn plants should take into account any possible differences in stand due to the organism in question. In the University Farm test for 1929, the probable error is high due to the scarcity of available seed, which limited the experiment to two plats of each strain. The general tendency is in the direction of increasing yield per plant as the space between the plants is increased. Strain 66, the lowest yielding strain in the test, yielded only 15.3% more per plant when spaced 3 feet apart, as compared to 1 foot apart. Strain 63, the second lowest yielding strain, showed no increase in yield for 3-foot as compared to 2-foot spacing of single plants. It seems probable that 2-foot spacing of single plants for the less vigorous strains allows for maximum development. For the more vigorous strains 3-foot spacing permits more growth per plant than 2-foot spacing. Reasoning from these results, it appears doubtful if competition extends much, if any, beyond the 3-foot spacing.

It is apparent from both University Farm and Waseca results that when hills have reduced stand or are adjacent to hills lacking in

stand and are harvested in a variety test, a rather large error may be introduced.

In 1929, at University Farm, with an average yield for the dent crosses of 59.2 bushels per acre, there was considerable response due to adjacent hills with reduced stand, whereas in 1928 with an average corresponding yield of 46.8 bushels, there was very little response. The data suggest that the response due to missing hills or to hills with reduced stand may vary considerably from year to year, and that there may be a correlation between the response obtained and the yield. The results for 1928 indicate a possible difference in the reaction of flint and dent strains for the conditions of the experiment. Two-plant hills at University Farm between two blank hills in 1928 yielded only 85.0% of perfect stand as compared to 86.7% for 1929 when the 2-plant hills were bordered on all four sides by a full stand.

At Waseca with yields for the crosses about the same each year, the increase due to missing hills was similar for the two years, and the same may be said for the decreased yield of 1-plant and 2-plant as compared to 3-plant hills. As an average for the two years, the increase in yield of 3-plant hills due to one or two adjacent blank hills was 5.6% and 8.9%, respectively, whereas the decrease in yield of 2-plant hills compared with 3-plant hills amounted to 24.6%.

SUMMARY

1. In order to determine the sources of error in harvesting plat trials with selfed lines and crosses of corn, an experiment was conducted at University Farm, St. Paul, and at Waseca, Minnesota, for the two years, 1928 and 1929. Selfed lines of dent varieties and single and double crosses of both flint and dent varieties were used at St. Paul, while at Waseca only selfed lines and single crosses of selfed lines of Silver King dent corn were used.

2. With six selfed lines in the University Farm test, the average yield per plant for 3-plant hills, 3½ feet apart, was 91.7% of that for single plants spaced 1 foot apart.

3. Single plants of selfed strains, when planted 3 feet apart, gave an average increase, at University Farm, of 35.7% over 1-foot spacing in the row, while 2-foot spacings have a 17.3% increase. The data indicated that the less vigorous strains attained maximum growth at less than 3 feet apart in the row.

4. At Waseca the selfed lines were planted in hills 3½ feet apart each way. There was evidence of competition, one blank hill adjacent to a 3-plant hill resulting in a 6.0% increase in yield of that

hill, while two adjacent blanks gave a corresponding 5.5% increase as an average for two years. Apparently, two blank hills resulted in no greater increase than a single blank hill. One-plant hills yielded only 39.9% as much as perfect-stand hills.

5. With single crosses at University Farm in 1928, the average yield of a 3-plant hill when adjacent to two blanks hills, one blank hill, and one 2-plant hill with blanks on the corners was increased 12.6, 7.0, and 4.8%, respectively, over the yield of 3-plant hills which had competition on all sides. Similar comparisons were made with double crosses in 1929 for 3-plant hills adjacent to two blanks, one blank, and one 2-plant hill, with corresponding increases of 13.1, 16.2, and 3.8%. The six dent crosses gave practically no increase in 1928, while two flint crosses showed marked response to extra room for development.

6. At University Farm in 1928, 2-plant hills with blank hills on two corners yielded 85% as much as 3-plant hills surrounded by a full stand. In 1929, 2-plant hills surrounded by a full stand yielded 86.7% as much as corresponding 3-plant hills.

7. The results obtained for crosses at Waseca were similar for the two years. As an average of both years, failure to discard single 2-plant, 1-plant, or blank hills resulted in losses of 15, 40, and 67%, respectively, in yield from the space allotted to the hill with deficient stand over a 3-plant hill.

8. Two-plant hills of F_1 crosses yielded 24.6% less than 3-plant hills, at Waseca, as an average of both years. At University Farm in 1929, 2-plant hills yielded 20.6, 8.4, and 16.2% less than 3-plant hills for the dent, flint-dent, and flint crosses, respectively, or an average of 13.3%.

THE ACTION OF TOXIC AGENTS USED IN THE ERADICATION OF NOXIOUS PLANTS[1]

R. B. HARVEY[2]

The substances now used for killing noxious weeds and shrubs may be classified on the basis of their type of toxic action as follows: First, substances which by their osmotic action plasmolyze cells and prevent plants which are treated with them from obtaining water. An example of such substances is common salt. A second class includes those substances, such as hydrocarbons, which by their physical action dissolve or dilute protoplasmic constituents and disorganize the cell by changing its permeability and other physical properties. A third type includes the protoplasmic poisons which stop the action of enzymes, coagulate protein, or combine with other constituents of the protoplasm. Examples of this class are mercuric chloride, cyanides, copper salts, ferrous sulfate, etc. Recent work of the author indicates that this is a type of action exhibited by certain substances which react with the respiratory pigments of plants and interfere with the oxidation-reduction balance in cells. An example of this class is sulfur dioxide, which causes the reduction of respiratory pigments so that they can no longer function. Other agents of this type will be discussed later. All of these types may be shown by a substance, the main action being that which comes to expression at the lowest concentrations. For instance, mercuric chloride has an osmotic action, but this does not come into effect generally because the effect of the mercuric ion as a coagulant of proteins occurs at much lower concentrations.

To use the osmotic action for killing plants requires that the concentration of the solution shall be rather high, at least higher than the osmotic concentration of the cells of the plant to be killed. The usual range of osmotic pressure in plants is from 5 to 20 atmospheres, but osmotic concentrations of some halophytes may be as high as 161 atmospheres. Dry seeds may be able to imbibe water against a force of nearly 1,000 atmospheres of osmotic pressure. Large quantities of the plasmolyzing agent are required to kill, and to be useful for an eradicant the substance must be very inexpensive.

The use of pure saturated hydrocarbons, gasoline, or oils to eliminate plant pests is dependent upon penetration and conduction

[1]Contribution from the Division of Plant Pathology and Botany, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Journal Series Paper No. 990. Received for publication January 7, 1931.

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into the plant in concentrations sufficient to kill. The plant cell is principally water, and to have more than a local action the hydrocarbons must either be soluble in water or penetrate in the gaseous condition.

Of the protoplasmic poisons, those which coagulate proteins, such as salts of the heavy metals, are quite effective for use on thin layers of tissues, such as leaves, but where masses of tissue are concerned their action as protein coagulants prevents their penetration deep into the tissue. A considerable quantity of salts of the heavy metals is required because the metallic ions are combined with and precipitated by the proteins. Also, salts of the heavy metals are held by the soil and may have a lasting effect on soil fertility.

The substances which act by disarrangement of the oxidation-reduction system of cells seem to be of two types. First are those, like sulfur dioxide, which are strongly reducing substances which reduce the oxygen acceptors of tissues so that they are unable to combine with oxygen. Tissues treated with sulfur dioxide do not turn darker on exposure to air. The respiratory chromogens evidently are reduced to such a state that they no longer serve as carriers of oxygen. The other type of action is that shown by chlorates and ethylene oxide. The tissues turn black and the cells die. Evidently the respiratory chromogens are so completely oxidized that they cannot function. They are oxidized to the pigment forms peculiar to each tissue. Thus, the leaves, bark, and young woody tissues of popple turn black after treatment with solutions of ethylene oxide and of sodium chlorate. The tissues quickly die, and the extent of the killing can be judged by the blackening of the tissues.

The quantity of respiratory chromogens present in cells is not great, so the quantity of toxic agent required to upset the oxidation-reduction conditions of the cell is not great. The use of chlorates on Canadian thistle (*Circium Arvense*) has shown the blackening of leaves and stems within 48 hours after spraying chlorates upon them. The roots of leafy spurge (*Euphorbia esula*) turn black on treatment with ethylene oxide.

In 1924, during the investigations of this laboratory on the ripening of fruits and vegetables and the blanching of celery by means of ethylene gas, ethylene oxide was tried as a ripening agent. On September 10, bananas treated with ethylene oxide, 1 part in 1,000 parts of air, did not ripen but turned black very quickly. The skins were very black in 24 hours after treatment, and the flesh was blackened along the vascular tracts. The use of ethylene oxide as a ripening agent was abandoned. In October, 1924, trial was made of the

toxic effects of ethylene oxide on animals. A rooster was placed in an atmosphere containing ethylene oxide, and the concentration was gradually increased in the chamber until the rooster seemed to be anaesthetized. Then he was brought out into the open air. His comb turned very dark in color and he died. The toxic effect of ethylene oxide was evident.

Ethylene oxide was tried also for its use in breaking the dormancy of potato tubers. All tubers treated with ethylene oxide turned black and the tissue was killed. The use of ethylene oxide to break dormancy was abandoned.[3]

Among a large number of substances which were tried for their effectiveness in the eradication of noxious weeds, it was decided to include ethylene oxide. On December 10, 1929, a pan of quack grass was treated with a 10% solution of ethylene oxide in water, using 300 cc of this dilution in a galvanized iron pan 10 inches wide, 12 inches long, and 4 inches deep, filled with quack grass sod. The rhizomes were all killed, but on February 10 it was noticed that quack grass seed and weed seeds had sprouted in the same soil. This indicated that ethylene oxide was an effective killing agent, but that its effect was not lasting in the treated soil.

On April 19, 1930, barberry bushes growing on the grounds of the State Agricultural Society were treated with ethylene oxide, pouring the liquid from a graduated cylinder into a hole made beneath the bush. One bush with eight stems about 3 feet high was given 30 cc of ethylene oxide. The crown of this bush was 6 inches from a Crataegus tree. On June 18 all but two sprouts nearest the Crataegus were dead while, the Crataegus tree was uninjured. A smaller bush with four shoots 2 feet high was also given 30 cc on April 19. A Crataegus tree was 1 foot away from the bush. On June 18 both the barberry and the Crataegus were killed. Evidently the placing of the charge determined the range of the killing area.

Various devices were then tried for injecting the ethylene oxide into the soil and for measuring the dose. On August 12 a group of 16 large barberries was found at Afton, Minnesota, and was treated with ethylene oxide and diethylene oxide, measuring different doses into holes made by a rod under the bushes. On one bush in this group, which was given 0.4 kilo of a mixture of 500 cc of ethylene oxide with 4,500 cc of water, only the young stems and some leaves were dead and blackened August 19. On September 17 all of the leaves on this plant were dead except those on a single branch op-

[3]This was reported in a paper by Vacha and Harvey in Plant Physiology, 2: 187–193. 1927.

posite the point of injection of the ethylene oxide. These were browned and reddened along the veins, evidently due to the production of anthocyanins. A second bush showed some green leaves

FIG. 1.—Barberry branch, showing blackening of the cambium layer 8 days after treating with ethylene oxide.

on one side. Seven other bushes in this group were all dead on September 17. The cambium and inner bark and younger wood were blackened, as shown in Fig. 1. The leaves also blacken when the dose is large enough to kill (Fig. 2).

FIG. 2.—Barberry shoot, showing blackening of leaves 8 days after treating with ethylene oxide

The barberry eradication campaign and the campaigns for the control of white pine blister rust through the eradication of currants and gooseberries have shown the need of a chemical substance with high toxicity to the noxious plants yet which will have no lasting detrimental effect on the soil. Ethylene oxide seems to be such a substance. The practice of digging out barberry bushes leaves a possibility of sprouts being produced from pieces of roots not removed in the digging. The use of common salt is a more desirable practice from the standpoint of the labor involved and the effectiveness of the killing agent. For use in pastures this method may have some objection. The use of chlorates, arsenates, etc., is excluded in pastures where cattle may be poisoned.

By the use of a rod, ethylene oxide can be introduced into the soil beneath bushes or into layers of soil below the plow sole. A "depth charge" can be regulated to certain levels of roots in the soil. The materials so injected are not accessible to animals. Ethylene oxide is liquid at ordinary temperatures at pressures between 8 and 20 pounds per square inch. This gives pressure sufficient to drive it into the soil directly from the tank. A special measuring device fitted to an injecting rod has been devised, which has been called a "gopher stick."

The ethylene oxide is volatile enough to allow a quick spread through the soil. A relatively short period of its effect in the soil is indicated by results so far obtained. It is soluble in water, and

dilutions with ice cold water can be made with little loss when it is desired to use a water dilution or a mixture with other toxic agents.

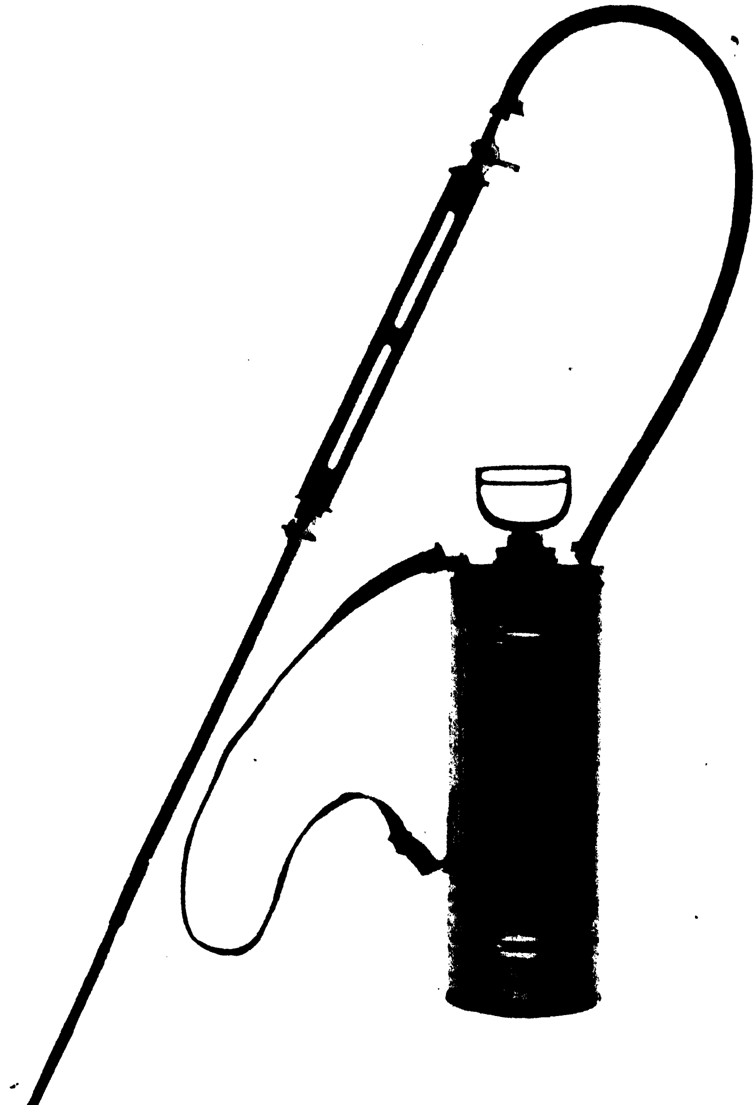

FIG. 3.—"Gopher stick" on a knapsack sprayer.

Dilutions can be handled in the usual knapsack sprayer, with a "gopher stick" (Fig. 3) in place of the spray nozzle. Mixtures with

chlorates or formaldehyde can be used without chemical reaction destroying the toxicity.

The use of ethylene oxide alone and in water solution to date has been shown by the killing of several hundred bushes of barberry, currant, gooseberry, poison ivy, prickly ash, scrub oaks, popple, boxelder, etc. The size of the charge or dose must be adjusted to the bush to be eradicated. Determinations have been made on the charge required in different types of soils and with various soil moisture contents. Indications are that at the present price of ethylene oxide the cost of materials is about the same as for eradication by common salt, while the labor is considerably reduced.

The practical applications of ethylene oxide under various conditions have shown that the action can be localized so as to kill roots which lie deep in the soil without killing plants whose roots are shallow. By placing a depth charge of the ethylene oxide 18 inches below the surface near roots of barberry, it has been possible to kill the bushes without killing grass around them. There may be some disadvantage in not killing seedling barberries just starting beneath the bushes.

For shallow-rooted shrubs, such as hazel brush, it is desirable to put the charge beneath the mat of roots to decrease the loss of the ethylene oxide from the soil. Perhaps ethylene oxide will not prove effective as an eradicating agent for shallow-rooted weeds, such as quack grass, on account of its rapid diffusion from the soil. When sprinkled in water dilutions onto quack grass sod, little killing effect is shown. Higher members of the oxides of unsaturated hydrocarbons, such as propylene and butylene oxides, have a decreased volatility and may be more useful for this purpose.

Diethylene oxide is less volatile than ethylene oxide, but comparative tests run under the same conditions show the diethylene oxide to be not injurious to plants treated with quantities such as were found lethal in the use of ethylene oxide.

Propylene oxide (B. P. 35° C) is less volatile than ethylene oxide (B. P. 10.5° C). This may decrease its penetration through the soil as a gas. Propylene oxide is soluble in water and may move with the soil water and be absorbed by the roots. Propylene oxide has been applied to potted barberries and other plants and on a few plants in the field. In the field trials evidently the concentrations were too low to give observable effects, but in the greenhouse pot experiments the toxic doses show injury of the same nature as ethylene oxide and at approximately the same doses. Fig. 4 shows the effect of graduated doses of propylene oxide in killing barberries. The

tissues of the cambium are blackened and the leaves show reddening or blackening and then drop off much as in the treatment with ethylene oxide.

Flats 18 x 16.4 inches were filled with moist soil, and to each was added 100 cc of ethylene oxide or propylene oxide dissolved in water. Dry seeds of wheat, peas, radish, corn, and oats were planted in these flats on the same day that the oxides were applied and on the second, third, and fourth days after. Seeds planted on the first day were nearly all killed by both ethylene oxide and propylene oxide. There was injury to those planted on the second and third day after treatment, but those planted on the fourth day gave normal seedlings. On account of the shallowness of the layer of soil, it will be necessary to try out the treatment under field conditions with various crops before conclusive data can be obtained, but the indications are that the effect of the oxides of the unsaturated hydrocarbons is much less lasting than the effects of chlorates.

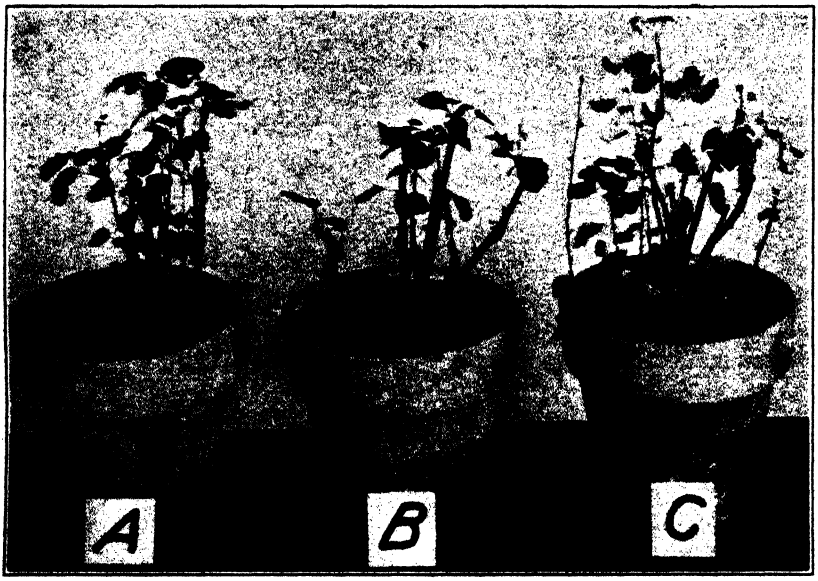

FIG. 4.—Potted barberries treated with propylene oxide. A. 0.1 cc propylene oxide, no apparent injury. B. 1.0 cc propylene oxide, some injury on leaves. C. 10.0 cc propylene oxide, plant dead.

These oxides of unsaturated hydrocarbons may be manufactured from natural gases or from gases produced in the cracking of petroleum. These gases are waste products in some regions. The process of manufacture is relatively simple, being first a chlorination of the

unsaturated hydrocarbons in water to produce ethylene or propylene chlorhydrin. On treatment with alkali, the chlorhydrin yields the corresponding oxide. The chlorine and alkali are easily produced from common salt by electrolysis. The availability of cheap electrical power, as at Muscle Shoals, near a supply of waste unsaturated hydrocarbons, as in West Virginia, should make these oxides inexpensive. Their toxicity in low concentrations seems to open up possibilities for them in the general eradication of the more noxious deep-rooted weeds. The ease of handling these oxides is much greater than for common salt or the chlorates. This is of especial advantage in woods or rough country where the materials must be carried. A man can carry easily the 17-pound cylinder (total weight, 40 pounds) in an army pack sack. This is enough to treat more than a hundred bushes of barberry or gooseberry.

The action of these oxides seems to be upon the respiratory mechanism of cells. Treatment of tissues with ethylene or propylene oxide decreases catalase and oxidase activity. The blackening of the tissues is evidence of the oxidation of the respiratory chromogens.

SUMMARY

Ethylene and propylene oxides were found to be useful eradicants for noxious plants. They offer advantages over present methods in ease of handling, in toxicity in small concentrations, and in rapid release from the soil, thereby decreasing the time of unproductivity in comparison with chlorates and chlorides.

THE EXTENT OF VICINISM IN COTTON AT CLEMSON COLLEGE[1]

Gilbeart H. Collings and R. W. Wallace[2]

As the pollen grains of cotton are sticky and adherent, it is probable that very little wind pollination of cotton takes place. On the other hand, as has been shown by Ware (4)[3] and others, cotton is pollinated easily by insects. The extent of insect pollination of cotton and its resulting influence on the mixing of cotton varieties in any locality must depend largely upon the kinds and number of insects present and the number of visitations made by the insects to the cotton flowers.

McLendon (3) is of the opinion that no pedigree can be considered trustworthy after a variety has been subjected to the agencies which cause cross pollination in localities where other varieties of cotton are being grown. He believes that cross fertilization may be as much as 40%, but that under average field conditions it is not much less than 10%.

Kearney (2) found that the presence of vicinists may exceed 20%, but that it is generally lower. Ware (4), at Fayetteville, Arkansas, found the amount of natural crossing in both red and green plants to be 40.9%. On the other hand, Gammie (1) reported that the prevalence of natural crossing of cotton in India is of very rare occurrence.

During the last season an excellent opportunity to determine the extent of cross fertilization of cotton arose at the Clemson Agricultural College. Two farmers in the vicinity of the college had planted fields of a red-leaf variety of cotton, which is seldom grown in this state, and which is known locally as Red Leaf. One field, which hereafter will be designated as Field A, was nearly surrounded by green-leaf varieties of cotton. No cotton bordered it on the southwest. The other field, which hereafter will be designated as Field B, had green-leaf cotton adjacent to it on the east only.

Advantage was taken of this coincidence and where possible seed cotton was picked from rows of the green-leaf varieties at approximate distances of 10, 20, 30, 40, 50, 100, 150, and 200 feet in several directions from the field of the red-leaf cotton. The seed cotton was then ginned by hand and preserved for future study.

[1]Contribution from the Department of Agronomy, South Carolina Agricultural Experiment Station, Clemson College, S. Car. Received for publication January 8, 1931.

[2]Associate Professor of Agronomy and Assistant Agronomist, respectively.

[3]Reference by number is to "Literature Cited," p. 492.

McLendon (3) and Ware (4) have shown that the red color characteristic of the leaf is incompletely dominant over the green leaf. All plants produced in the F_1 generation are dilute reds. It was necessary, therefore, to determine only the percentage of red plants in the F_1 generation of the green-leaf cotton in order to obtain the relative extent of hybridization that had taken place.

Preliminary tests dealing with the germination of seeds from Red Leaf plants showed that the red coloring matter was present in the hypocotyl and that red seedlings could be detected as soon as the seed germinated. It was not necessary, therefore, to plant the seed and grow the seedlings under field or greenhouse conditions.

TABLE 1.—*Analysis of samples taken from field A.*

Direction from Red Leaf cotton	Distance from Red Leaf cotton, feet	Germination %	Percentage of red-leaf plants
West	10	99	00.00
West	20	97	00.00
West	30	70	00.00
West	40	99	00.00
West	10	100	00.00
West	20	98	00.00
West	30	97	00.00
West	40	98	00.00
West	50	100	00.00
West	100	99	00.00
West	150	97	00.00
West	200	89	00.00
Southeast	10	99	3.03
Southeast	20	94	00.00
Southeast	30	95	00.00
Southeast	40	100	1.00
Northwest	30	100	00.00
Northwest	40	97	2.06
Northeast	10	96	2.08
Northeast	20	100	00.00
Northeast	30	98	1.02
Northeast	40	99	00.00
Northeast	150	98	00.00
Northeast	200	100	00.00

TABLE 2.—*Analysis of samples taken from field B.*

Direction from Red Leaf cotton	Distance from Red Leaf cotton, feet	Germination %	Percentage of red-leaf plants
East	10	98	00.00
East	20	99	4.04
East	30	100	2.00
East	40	98	1.02

The seed secured from the fields of green-leaf cotton were germinated in a seed germinator and the percentage of red seedlings determined for each locality from which the seed had been taken. In Tables 1 and 2 are given the percentages of germination and the percentages of red plants found for each locality studied.

Of a total of 2,705 seeds germinated, only 16 seedlings were found to be hybrids. If it is assumed that the samples of seed collected were representative of that area of the green cotton field within 200 feet of the Red Leaf variety, then, as an average for all tests, we have a percentage of vicinism of only 0.59. This is very much lower than had been anticipated.

The prevailing winds during the greater part of the flowering period were from the west. There is no strong evidence in the results secured to indicate that the prevailing winds during the flowering period had any marked influence on pollination. The cross fertilization that took place must have been due almost entirely to insects.

Out of a total of 28 localities studied, only 8 showed the presence of vicinists and in only 1 case was the percentage of vicinists as high as 4. No vicinists were found at distances greater than 40 feet from the field of Red Leaf cotton.

Kearney (2) has made a similar study and found that the percentage of cross fertilization was about the same for any row up to and including the 50th row from the field of Red Leaf cotton. Studies dealing with the percentage of vicinists in rows further removed were not made.

If the results here presented are a fair criteria of the extent of cross fertilization to be expected during an average year between adjoining large fields of dissimilar varieties of cotton, then the presence of a few undesirable plants in a field is not as serious as many have assumed. A few undesirable plants scattered through a field of cotton do not bring about a rapid deterioration, although in time the homogeneity of the variety must be sacrificed. It is apparent that we must look elsewhere for the principal cause of the mixed cottons which are found in the average community.

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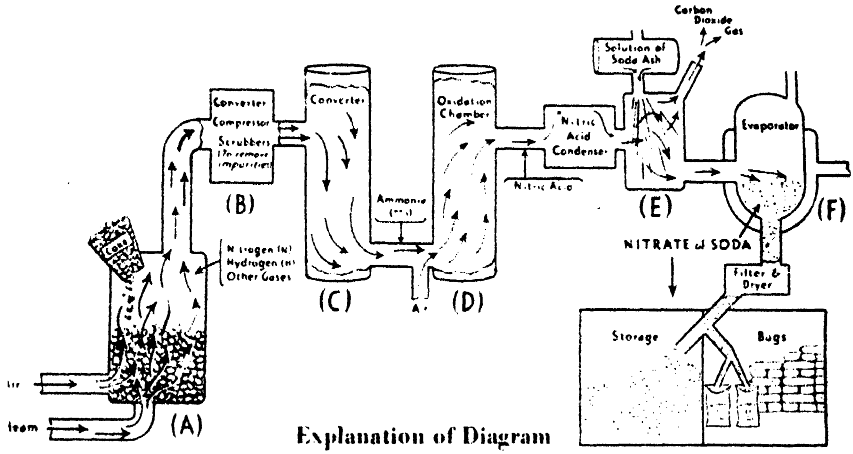
NOTES

NITROGEN FIXATION IN THE UNITED STATES

Research by the fixed-nitrogen laboratory of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, is reflected in the progress of the fixed-nitrogen industry of the United States, whose output in 1929 was more than three times that of the preceding year, according to the 1930 Annual Report of the Secretary of Agriculture. The bureau's contribution to air-nitrogen fixation in the United States is not measurable solely in research results, but includes also a contribution of personnel to the industry. Many scientists who began their studies of the problem in the government laboratory are now leaders in the commercial field. The government began the study of air-nitrogen fixation about 15 years ago. Progress is now rapid in both research and practice.



Explanation of Diagram

In (A) air, containing the Nitrogen, and steam are blown through glowing coke, producing a number of gases including Nitrogen and Hydrogen. (B) indicates converters and compressors, and "scrubbers" to remove impurities from the Hydrogen and Nitrogen gases; in converter (C) the Hydrogen and Nitrogen are combined, under pressure and heat, to make Ammonia gas which passes into another converter (D) where it is burned with air (oxidized) to make Nitric Acid, when Nitric Acid reacts, as in mixer (E), with a solution of soda ash it forms a neutral or slightly alkaline solution of Nitrate of Soda and liberates carbon dioxide gas; the Nitrate of Soda solution is evaporated in (F); then the Nitrate is filtered and dried, and is conveyed to storage or put in moisture-resisting bags for shipment. While one of the raw materials comes from the air, the process also requires steam, coke, and soda ash, and the plant equipment is costly and complicated. Even though the Nitrogen is drawn from the air, large expense must thus be incurred before sodium nitrate in finished form is ready for shipment. The final product is practically pure Nitrate of Soda containing 16 per cent Nitrogen (guaranteed analysis) and having less than two-tenths of one per cent moisture.

FIG. 1.—Principal steps in processes for the fixation of atmospheric nitrogen as nitrate of soda.

Output of inorganic nitrogen by the air-fixation process in the United States was 84,000 tons in 1929, as compared with 26,000 tons in 1928 and 5,900 in 1923. The output for 1930, according to more recent data, is given at approximately 140,000 tons. These figures may be usefully compared with the output of by-product nitrogen, which was 187,600 tons in 1929, 170,000 tons in 1928, and 123,500 tons in 1923. Inorganic nitrogen is obtained from three sources, *viz.*, imports, the by-product process, and air fixation. The foregoing figures show the rapid relative advance of air fixation. Domestic production in 1926 furnished 60.5% of our supply of inorganic nitrogen, as compared with 49.5% in 1923.

One of the most modern of the processes now in use for the fixation of atmospheric nitrogen is that employed at Hopewell, Virginia, where America's largest air nitrogen plant is located. This plant makes not only ammonia but also nitrate of soda, which is produced in white, granular crystals containing 16% available nitrogen and which is dried to contain less than 0.2% moisture. It is recommended by state and federal agricultural authorities for top-dressing and side-dressing purposes and for mixing in complete fertilizers on the same basis as other nitrate of soda.

The accompanying diagram (Fig. 1) shows the principal steps in processes for the fixation of nitrate of soda.

MAGNESIUM—A POSSIBLE KEY TO THE PHOSPHORUS PROBLEM IN CERTAIN SEMI-ARID SOILS

In recent years, it has been found that some soils of North Dakota respond favorably to phosphate fertilizers while others do not, even though crop yields be low and the content of readily available phosphorus be no more, or even less, than the responsive soils. Recent greenhouse trials with barley on a Fargo clay soil which has grown wheat continuously for 40 years, with nothing returned, have indicated a large response to magnesium oxide. The plants receiving magnesium oxide headed two weeks earlier, had more tillers, larger and stronger straw, and much larger heads of grain than other plants. Lime and other materials containing nitrogen, potassium, and phosphorus gave only small increases in comparison. Although this soil has been cropped to wheat continuously for 40 years, it is not infertile as indicated by the fact that for the past 14 years yields have averaged about 16 bushels per acre and the present supply of readily available phosphorus is high. A further experiment with a similar Fargo clay which has been cropped to a rotation with residues returned shows a like response to magnesium oxide.

It is well known that magnesium is an essential element and that one of its functions is in connection with phosphorus nutrition, probably as a phosphorus carrier. It may not be necessary that phosphorus enter the root as magnesium phosphate, but its movement and especially its final delivery at the point of utilization within the plant are more effective and rapid if in that form. During the ripening period phosphate is deposited in the seed as magnesium phosphate so that the young plant will have phosphate in a form immedi-

ately usable. In soils very deficient in soluble magnesium compounds, plants may actually suffer from a lack of phosphates in proper form. Magnesium hydroxide is so very insoluble that it is not to be expected that plants will be able to obtain sufficient quantities of this element by simple hydrolysis of the carbonate. Calcium carbonate would tend, therefore, to suppress the availability of magnesium, while calcium sulfate, by double decomposition, would have the effect of rendering the magnesium more available in the form of the very soluble magnesium sulfate. This is borne out in the results obtained with barley, as calcium sulfate gave the greatest increases excepting the magnesium oxide.

These facts may be a factor in explaining the present low yields of flax in much of the northwest. Plants bearing oleaginous seeds are especially in need of magnesium phosphate for seed production. Applications of ordinary fertilizers on flax have not been successful up to now.

Many calcareous soils of the semi-arid regions that have what appears to be a high content of readily available phosphorus respond to heavy applications of phosphate fertilizers. It is quite possible that in some of these cases magnesium is limiting, and improved phosphorus nutrition is brought about by the addition of extremely large amounts of readily available phosphorus, and also by the calcium sulfate introduced in superphosphate. It is also possible that some of the crop increases obtained by sulfur fertilization can be attributed to the influence of these materials on the solubility of magnesium.

These facts may account for the apparent, frequent failure of laboratory methods to diagnose properly the phosphorus needs of semi-arid regions. In the absence of adequate soluble magnesium compounds, proper phosphate nutrition cannot be realized, even though a considerable amount of readily available phosphorus is present in the soil.

The writer has further studies of this magnesium-phosphorus relationship under way with the view of determining the amounts and kinds of materials needed for a proper balance with various crop plants.—CHAS. E. KELLOGG, *North Dakota Agricultural College, Fargo, N. Dak.*

AGRONOMIC AFFAIRS

NEWS ITEMS

ON SEPTEMBER FIRST, this year, the Agronomy Department at the University of Wisconsin will occupy the new four-story building which is now under construction. During the past 24 years the work of the Department on grain breeding, forage improvement, organic nutrition of plants, hardiness and other physiological studies has expanded to the point where the old building no longer suffices to meet the growing needs of the agronomic work. The new building is being planned and equipped for emphasis on graduate and research work. In addition to the Agronomy Department, the new Agronomy building will be occupied by the Department of Plant Pathology and the State Seed Inspection Division.

THE EXECUTIVE COMMITTEE of the American Organizing Committee of the first International Congress of Soil Science announces that after July 1, 1931, the price of sets of the Proceedings of the first Congress will be increased to $5.50 per set to members of the Society in the United States and $6.50 per set to members in foreign countries.

DR. FRED GRIFFEE, for some time Assistant Director of the Maine Agricultural Experiment Station and Biologist in charge of plant breeding, has been made Director of the Station to fill the vacancy occasioned by the death of Dr. W. J. Morse.

DR. W. H. JORDAN died at Orono, Maine, on May 8. Dr. Jordan was for eleven years Director of the Maine Experiment Station and for twenty-five years Director of the New York State Experiment Station. Prior to taking up his duties at the University of Maine, he was Professor of Agricultural Chemistry at Pennsylvania State College where he laid out the soil fertility plats, the fiftieth anniversary of which is to be celebrated this month. It had been expected that Dr. Jordan would be the guest of honor at this celebration. Although many of his contributions were to the science of nutrition, both human and animal, at the same time he engaged in a considerable amount of agronomic research; not only in Pennsylvania but in Maine and New York as well.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 JULY, 1931 No. 7

THE EFFECT OF SOIL TYPES AND FERTILIZERS ON YIELD AND QUALITY OF FIBER FLAX[1]

B. B. ROBINSON AND R. L. COOK[2]

Many investigations have been conducted on the effect of fertilizers on the growth and development of the flax plant. Most of them have been in Europe, where the soil types and environmental conditions are not similar to those in the United States. To the Germans and Russians must be credited most of the work along this particular line, but valuable additions have been made from other sources, especially Ireland. Unfortunately, the Russian work has been somewhat inaccessible, due to the articles appearing in periodicals which are not found in most libraries and to the difficulties with the language encountered by most workers. The foreign experiments form the foundation for work in this country and help very much in the proper interpretation of the results presented in this article.

At one time it was believed that flax was very hard upon the soil; that is, that when flax was grown, it rapidly depleted the soil of its plant food elements. This belief was proved to be incorrect by several investigators, including Ince (7)[3], who showed that flax takes no more plant food from a soil than many of the common farm crops. This idea was probably most prevalent in America where it was noticed that in some instances when flax was planted on the same field two years in succession the second crop was inferior. Now it is

[1]Joint contribution from the Departments of Farm Crops and Soils, Michigan Agricultural Experiment Station, East Lansing, Mich., and the Office of Fiber Plants, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Michigan Agricultural Experiment Station Journal Article No. 56 N. S. Received for publication January 21, 1931.

[2]Assistant Plant Breeder and Research Assistant in Soils, respectively. J. D. Romaine and G. R. Schlubatis, formerly of the Soils Department, and G. M. Grantham and A. G. Weidemann, Soils Department, aided in performing some of the field work.

[3]Reference by number is to "Literature Cited," p. 509.

known that the deterioration in yield was probably due to flax wilt (*Fusarium lini*). This fungus, which lives in the soil, caused a large percentage of the plants to die. In recent years wilt-resistant varieties have been developed.

This paper deals with a study of the effect of soil type and fertilizer on the total yields of straw, fiber, and seed; the percentage of fiber in the straw; and the quality of the fiber. Field tests were made on four different soil types, each experiment covering a period varying from one to four years.

REVIEW OF LITERATURE

The only investigations in America with particular regard to the fertilization of fiber flax are those of Powers (12) in Oregon and Hutchinson (6) in Canada. Powers came to the conclusion that potash salts may be expected to increase the length and the value of fiber flax and that the potassium ion may play a catalytic rôle in synthesis of carbohydrates or function to keep simpler carbohydrates in solution until they can be deposited in the transforming bast fibers in the flax plant. Hutchinson's four years of work shows there is little to be gained by applying fertilizers to flax when this crop is grown in a fairly rich clay loam soil and in a regular rotation with other farm crops.

Tobler (14, 15) emphasizes the importance of making anatomical studies of the bast cells when studying the effect of fertilizers and states that the shape of the bast cells, which influence the quality of the fiber, has generally been attributed to hereditary characters but is more likely to be the result of the soil nutrients.

Gross (5) obtained no beneficial effects when nitrogenous salts were supplied in addition to potash salt, but explains that his experiments were in an extremely dry year. Bredemann and Fabian (1) and Fabian (4) explained that a medium amount of nitrogen is desirable for the best quality and yield of fiber and that both a smaller or a larger application of nitrogen would produce less valuable returns. A deficiency of nitrogen is conducive to the production of short fine stems containing little fiber, while abundant nitrogen in the soil tends to produce thick stems with lower fiber percentages and fiber of a low quality, due to the cells being non-uniform and having large lumens.

Weck's (19) researches also led him to the conclusion that inferior fiber formation and fiber of poor quality result from nitrogen alone, but that these bad effects may be partly overcome with applications at the same time of potash and phosphate salts.

Kleberger (8) and Kuhnert (10) obtained increased yields of flax when nitrogen was applied in combination with other elements. Scheel (16) obtained increased yields of fiber with applications of nitrogen but lower long fiber percentages and higher short fiber or tow percentages.

The quantity and the particular form of the nitrogen in combination with other elements is another problem. General results indicate the quantity of nitrogen necessary depends very much upon the particular soil, but it should always be used cautiously and never in excess. Nitrogenous fertilizers are very likely to cause lodging and therefore are more applicable to short-strawed flaxes than to the long-strawed varieties. Tobler (13) states that, in general, ammonium sulfate is the best form in which to apply nitrogen.

Kulikova (11), experimenting with chemically pure nitrogenous salts in pot culture, ranged them with regard to their beneficial effect on the development of flax in the following diminishing order: KNO_3, NH_4HCO_3, NH_4NO_3, NH_4CL, $(NH_4)_2 SO_4$, $NaNO_3$, and $Ca(NO_3)_2$. Sodium nitrate has been mentioned as being too quick acting for flax, producing an undesirable effect upon the fiber.

Potash plays a very important rôle, as it appears to stand in definite relation to the fiber formation and the improvement of the quality of the fiber. Davin (2) proved the beneficial effects of potash on increasing the height of the flax and mentioned other work at the same institute to prove that a large number of relatively small fibers with a very little decrease in the percentage of fiber in cross section are correlated with increase in height. Further, she states there is the additional fiber in the extra height produced by the potash.

Bredemann and Fabian (1) showed that potash is especially beneficial where the soil is deficient in this nutrient. Further, it was very beneficial in counteracting the bad influence produced by an excessive quantity of a nitrogenous fertilizer. However, if the soil was rich in potash an application of potash as a fertilizer produced no detrimental effect on the fiber and did not increase the yield. Scheel (16) obtained increased yields of straw, fiber, and seed with potash applications and states that the stems were longer.

The appropriate form of potassium salt is not definitely known. Krafft (9) states that the chloride acted favorably, and this has been supported by others. Kleberger (8) obtained the most satisfactory results with kainite, and Tobler (13, 15) thought that potassium sulfate was the best. This problem was partially clarified by Steigerwald (18) who found that the chemically pure salts of potassium magnesium were better for seed yield than pure potassium chloride

salts. However, it was just the opposite for fiber yields as in that case the potassium chloride salts were the best. In explanation he states that the kainite gives a higher fiber yield than a treatment of potassium magnesium sulfate, because the chlorine content of the kainite is 24.8% in contrast to a 10.1% magnesium content, while the potassium magnesium sulfate has only 9.4% magnesium oxide and only 2.1% chlorine.

The effect produced by phosphate is not thought to be as marked as that produced by potash and nitrogen. It possibly acts more indirectly or in conjunction with the other elements. Davin's (2) researches showed that a marked increase in the percentage of fiber in cross section and in the fiber content of the flax plant took place with an application of phosphate, without causing any significant differences in the number and size of the fibers. Bredemann and Fabian(1) state that phosphate is slightly beneficial, but that sometimes it lowers the fiber quality, producing more tow in proportion to line fiber and that the fiber is reduced in strength.

Most investigators believe that fiber flax does best upon a neutral to slightly alkaline soil. Selle (17) states that an acid soil is most favorable to the activity of the nitrifying bacteria and that the superiority of an alkaline soil is only possible when it has a sufficient quantity of available nitrogen present. However, the idea of an acid soil being more favorable for the growth of nitrifying bacteria may be questionable. Bredemann and Fabian (1) state that a recent application of lime possibly has a retarding effect upon the flax growth, and Deterre (3) states that lime in excess gives a short fiber and that one should, therefore, always avoid applying lime immediately before sowing the flax.

EXPERIMENTAL

FIELD TESTS

The experiments were conducted on four soil types located in different parts of Michigan. The plats were laid out in the spring of 1926 for the purpose of determining the effect of fertilizers on the feeding quality of forage crops. Since space was available, flax was incorporated in the rotation.

Three of the fields, located on Miami, Hillsdale, and Isabella soils, having an acid reaction, were limed in the spring of 1926. The other field, located on Brookston soil, was neutral in reaction and was not limed.

The work on the Miami and Isabella soils was discontinued after one year, while the work on the Hillsdale soil type was continued for

three years and that on the Brookston soil type for four years. Brief descriptions of the different soil types follow:

Brookston clay loam soil has a very dark-gray friable silty clay loam surface soil extending to a depth of from 5 to 8 inches. The subsoil is bluish gray or dull gray, heavy, plastic clay or clay loam, often mottled with yellow or rust brown. This soil contains a high percentage of carbonates and in its natural condition is the most fertile of the four types used in the experiment. It has a very good moisture-retaining ability.

The surface layer of Miami loam is a grayish brown loamy material extending to a depth of 4 to 6 inches. Below this, to a depth of 6 to 10 inches, is a yellowish or grayish leached material that is somewhat heavier than the surface. The next horizon, extending to a depth of 36 to 40 inches, is a yellowish brown, compact, gritty, coarsely granular clay loam. The parent material, composed of compact, moderately stony, almost impervious bluish-gray glacial till, extends to a depth of several feet. This soil is acid on the surface and alkaline in the subsoil. It ranks next to the Brookston in natural fertility and moisture-retaining ability.

The Hillsdale type, in the virgin condition, is characterized by a surface layer of 3 to 4 inches of grayish brown loam or sandy loam. Below this is a pale yellowish friable sandy loam 10 to 15 inches thick. This material then grades off into a yellowish brown material from 18 to 24 inches thick, which contains large quantities of clay but which is still granular and friable. The upper horizons are acid in reaction and the soil is of average fertility.

Isabella sandy loam is characterized by a light brown surface soil to a depth of about 4 inches. Beneath this the soil is a yellowish light sandy loam to a depth of 20 to 30 inches. This grades into a reddish brown friable sandy clay. The surface soil is strongly acid in reaction. This soil is low in natural fertility and in moisture-retaining ability.

In all the experiments the field plats were 1 square rod in area and the fertilizers were broadcast each year before the flax was planted, with the exception that on the Isabella soil fertilizer was not applied in the spring of 1927. Thus, the differences upon Isabella soil were a matter of the residual effect of the fertilizer applied in 1926.

The flax seed was sown broadcast in some fields and was drilled solid in others. When the plants had reached a stage where approximately one-half the seed bolls were fully mature the flax was pulled and after drying was threshed.

LABORATORY STUDIES

After each plat of flax had been harvested, the straw was cured well before it was weighed and threshed. The threshed straw was weighed and later retted in water at room temperature (usually from

TABLE 1.—*Showing the yields obtained on Brookston soil over a period of four years calculated in pounds per acre, together with percentages of fiber and the fiber strength with its probable error.**

Treatments†	Manure	PSKN, 400	P	PS	PSK	PSKN, 200	PSKN, 800
			1927 Results				
Unthreshed straw	3,670	3,193	2,313	2,430	2,857	3,119	3,606
Threshed straw	2,190	1,953	1,540	1,600	1,837	2,006	2,260
Seed	482	380	293	270	404	424	515
Fiber, line	390	—	243	309	402	402	409
Fiber, hackled	81	—	55	53	68	95	111
% fiber	17.81	—	15.78	19.31	21.88	20.04	18.10
% hackled	20.77	—	22.63	17.15	16.92	23.63	27.14
Fiber strength	186.4	—	150.8	185.2	200.3	187.5	195.4
P. E. fiber strength	±5.3	—	±5.3	±6.0	±10.5	±5.7	±3.1
			1928 Results				
Unthreshed straw	5,492	2,766‡	6,292	6,276	7,318	5,234	5,847§
Threshed straw	4,260	2,209	4,931	4,830	5,750	4,160	4,540
Seed	344	150	389	429	488	368	507
Fiber, line	1,088	504	1,208	1,172	1,536	919	1,009
Fiber, hackled	335	186	257	343	510	312	387
% fiber	25.54	22.82	24.50	24.27	26.71	22.09	22.22
% hackled	30.79	36.90	21.27	29.27	33.20	33.95	38.35
Fiber strength	275.9	287.8	254.0	238.1	236.9	273.7	268.1
P. E. fiber strength	±6.1	±8.9	±4.3	±7.0	±5.2	±11.1	±6.1
			1929 Results				
Unthreshed straw	3,860	3,378	1,928‖	1,572‖	2,464‖	2,677	3,068
Threshed straw	2,819	2,386	1,330	1,056	1,742	1,945	2,219
Seed	393	372	205	195	294	322	374
Fiber, line	570	490	253	201	316	436	455
Fiber, hackled	291	229	79	55	120	232	193
% fiber	20.22	20.54	19.02	19.03	18.14	22.42	20.50
% hackled	51.05	46.73	31.23	27.36	37.97	53.21	42.42
Fiber strength	359.1	302.8	258.2	218.8	248.7	321.3	309.3
P. E. fiber strength	±4.5	±8.0	±7.3	±6.8	±6.4	±7.8	±7.2

1930 Results

Unthreshed straw	4,955	4,277	4,306	4,500	4,987	5,563	5,128
Threshed straw	3,331	2,843	2,896	2,988	3,475	3,825	3,493
Seed	656	598	612	699	757	823	787
Fiber, line	861	724	770	783	923	912	924
Fiber, hackled	553	458	456	480	496	510	526
% fiber	25.85	25.47	26.59	26.20	26.56	23.84	26.45
% hackled	64.23	63.26	59.22	61.30	53.74	55.92	56.93
Fiber strength	254.2	249.0	245.0	290.0	284.5	273.7	269.6
P. E. fiber strength	±10.5	±6.7	±8.7	±10.4	±8.2	±13.2	±8.7

*The fiber strength is measured in kilograms strength per gram of fiber 10 cm long.

†The fertilizer applications were as follows: Manure applied prior to 1926; check equivalent to no treatment; P = 200 lbs. 20% superphosphate; S = 200 lbs. of calcium sulfate; K = 100 lbs. of muriate of potash; N = the equivalent of 100 lbs. sodium nitrate applied as urea. In 1927, three different applications of phosphorus were made.

‡This column for check E in 1928, 1929, and 1930.

§This column for check W in 1928, 1929, and 1930.

||The flax was partly flooded after planting and this probably lowered the yields.

19° to 22° C). After the straw was completely retted, it was dried and later braked and scutched. The latter two operations were done carefully in order not to lose any fiber and also to treat each sample as nearly as possible in a similar manner. The scutching was done upon a special small scutching machine of the Lowry type. This machine cleaned the fiber very well and made no tow, but gave yields abnormally high as compared with flax scutched by the usual commercial methods.

The fiber was then hackled on the coarse hackles but not on the finest hackle. The fiber strength was determined by testing 10 samples of fiber from each plat. The fiber was taken from the center part of each lot, conditioned at 65% humidity, and broken on a Scott tester. The fiber strength is given in terms of kilograms strength per gram of fiber 10 cm long.

RESULTS

Tables 1 to 4 give the results obtained from field-grown flax in Michigan over a period of four years, 1927 to 1930, upon different soil types. The terms "unthreshed" straw yields and seed yields are readily understood by all, but some of the other terms are defined as follows: *Threshed straw*, because of the peculiar method used in threshing flax for fiber purposes, refers to weights of stems minus the seed and seed chaff. "*Line*" fiber here refers to total yield of fiber, which was in all cases approximately 99% straight or line fiber and only 1% tow. The *hackled fiber* is the total yield after hackling, which is a combing operation to remove short-length fiber or tow. The *fiber percentages* are calculated by dividing the yield of threshed straw into the fiber yield obtained. The *hackling percentages* are calculated by dividing the yield of line fiber into the yield of hackled fiber.

In interpreting the tables, it should be understood that the products which are ultimately sold are the fiber and the seed. Further, it is necessary to understand that in fiber flax the fiber is a much more valuable product than the seed. A pound of fiber will usually sell at 4 to 5 times as much as a pound of seed. However, the fiber will vary in price according to the quality, and this is very hard to determine by measurements, as it is more an art of judging quality than a science of measuring quality. In the experiments reported here the most valuable measurements that can be offered to indicate quality are the yields of fiber in the hackling process and the fiber strength. These two figures should give an indication of quality even if nothing else is known about the fiber.

TABLE 2.—*Showing the yields obtained on Hillsdale soil over a period of three years calculated in pounds per acre, together with percentages of fiber and fiber strength with its probable error.**

Treatments†	Check	Ca	CaMg, Mg	CaMg, P	CaMg, PS	CaMg, PSK	CaMg, PSKN
			1927 Results				
Unthreshed straw	1,473	1,438	1,229	1,406	1,582	1,699	1,759
Threshed straw	989	911	851	929	1,045	1,127	1,120
Seed	198	206	111	186	235	244	254
Fiber, line	188	145	168	193	203	263	233
Fiber, hackled	47	35	41	55	40	94	55
% fiber	19.01	15.92	19.74	20.78	19.43	23.34	20.80
% hackled	25.00	24.14	24.40	28.50	19.70	35.74	23.61
Fiber strength	170.3	136.0	171.2	159.2	177.7	223.9	185.7
P. E. fiber strength	±5.2	±3.8	±4.2	±3.4	±4.7	±7.0	±7.4
			1928 Results				
Unthreshed straw	2,953	3,179	3,610	3,373	3,391	4,298	4,397
Threshed straw	2,423	2,550	2,907	2,698	2,716	3,514	3,663
Seed	236	272	275	279	268	355	305
Fiber, line	523	538	674	606	587	790	755
Fiber, hackled	152	167	170	176	270	262	263
% fiber	21.58	21.10	23.19	22.46	21.61	22.48	20.61
% hackled	29.06	31.04	25.22	29.04	46.00	33.16	34.83
Fiber strength	231.2	207.5	230.4	206.4	232.8	243.8	243.2
P E. fiber strength	±6.9	±4.0	±4.3	±5.4	±2.3	±4.0	±5.4
			1929 Results				
Unthreshed straw	1,760	1,728	1,728	1,584	1,584	1,776	2,304
Threshed straw	1,144	1,077	1,074	971	982	1,144	1,505
Seed	301	280	322	234	365	324	394
Fiber, line	264	247	256	248	230	248	.334
Fiber, hackled	124	119	112	119	101	94	179
% fiber	23.08	22.93	23.84	25.54	23.42	21.68	22.19
% hackled	46.97	48.18	43.75	47.98	43.91	37.90	53.59
Fiber strength	273.1	264.4	267.5	226.4	256.2	271.2	254.7
P. E. fiber strength	±7.6	±9.3	±4.8	±9.8	±8.5	±4.6	±9.1

*The fiber strength is measured in kilograms strength per gram of fiber 10 cm long.

†The fertilizer applications were as follows: Check equivalent to no treatment; Ca = 2 tons calcium limestone; CaMg = 2 tons calcium-magnesium limestone; P = the equivalent of 200 lbs. 20% superphosphate as treble superphosphate; S = 100 lbs. sulfur; K = 100 lbs. of muriate of potash; and N = the equivalent of 100 lbs. $NaNO_3$ applied as urea.

TABLE 3.—*Showing the yields obtained in 1927 on Miami soil calculated in pounds per acre, together with percentages of fiber and fiber strength with its probable error.**

Treatments†	Check	Ca	CaMg	CaMg, P	CaMg, PS	CaMg, PSK	CaMg, PSK
Unthreshed straw	1,893	1,936	1,734	1,815	2,119	2,479	2,147
Threshed straw	1,208	1,219	1,091	1,095	1,399	1,579	1,409
Seed	322	302	285	324	289	359	311
Fiber, line	234	208	215	200	271	323	249
Fiber, hackled	59	45	58	42	94	83	66
% fiber	19.37	17.06	19.71	18.26	19.37	20.46	17.67
% hackled	25.21	21.63	26.98	21.00	34.69	25.70	26.51
Fiber strength	208.3	178.2	185.9	193.3	185.3	196.9	193.0
P. E. fiber strength	±6.6	±4.1	±5.1	±5.2	±6.9	±5.7	±7.2

*The fiber strength is measured in kilograms strength per gram of fiber 10 cm long.

†The fertilizer applications were as follows: Check equivalent to no treatment; Ca = 2 tons calcium limestone; CaMg = 2 tons calcium-magnesium limestone; P = the equivalent of 200 lbs. 20% superphosphate as treble superphosphate; S = 100 lbs. sulfur; K = 100 lbs. of muriate of potash; and N = the equivalent of 100 lbs. $NaNO_3$ applied as urea.

TABLE 4.—*Showing the yields obtained on Isabella soil in 1927 calculated in pounds per acre, together with percentages of fiber and fiber strength with its probable error.**

Treatments†	Check	Ca	CaMg	CaMg, P	CaMg, PS	CaMg, PSK	CaMg, PSKN	CaMg
Unthreshed straw	841	1,166	1,091	1,028	1,010	1,081	1,060	1,044
Threshed straw	530	742	664	643	636	742	656	639
Seed	134	177	186	170	162	186	203	188
Fiber, line	86	117	119	97	128	163	121	110
Fiber, hackled	21	20	25	13	27	43	24	33
% fiber	16.23	15.77	17.92	15.08	20.13	21.97	18.44	17.21
% hackled	24.42	17.09	21.01	13.40	21.09	26.38	19.83	30.00
Fiber strength	131.5	145.8	152.6	140.7	189.0	188.5	197.2	172.6
P. E. fiber strength	±5.2	±7.5	±4.7	±4.8	±4.8	±5.5	±8.4	±4.7

*The fiber strength is measured in kilograms strength per gram of fiber 10 cm long.

†The fertilizer applications were as follows: Check equivalent to no treatment; Ca = 3,000 lbs. calcium limestone; CaMg = 3,000 lbs. calcium-magnesium limestone; P = the equivalent of 200 lbs. 20% superphosphate applied as treble superphosphate; S = 100 lbs. calcium sulfate; K = 100 lbs. muriate of potash; and N = the equivalent of 100 $NaNO_3$ applied as urea.

The scutched fiber in nearly all cases when hackled gave a very low hackling percentage. This was the result of there being a large amount of tow in both ends of the fiber. Also, it may have been caused in part by the flax being retted until it was on the "soft side" to avoid the necessity of severe scutching to remove the wood. By this method the fiber determinations were obtained very accurately. These hackling percentages are really not as low as they seem to be if one understands that the calculations are based on all the fiber in the plant. In practice a great deal of fiber is made into tow in scutching and ordinarily this is not calculated into the percentage hackling yield.

INFLUENCE OF SOIL ON THE YIELD OF STRAW, FIBER, AND SEED

The Isabella soil proved to be entirely unsuited for flax and the experiments upon it were discontinued after the first year. Only the Brookston soil produced profitable yields. The data in Table 2 show that on Hillsdale soil only one year in three were yields comparable to those obtained by the average commercial flax grower.

In all of the results it is apparent that the greater yields were obtained upon the heavier soils and poorer yields upon the lighter soils. During a three-year period, as shown by the data in Tables 1 and 2, greater yields were obtained on the Brookston soil than on the Hillsdale soil. It is possible that not all of the differences can be attributed to soil type alone, as environmental conditions may have been slightly different due to the fact that the test plats were located from 75 to a 100 miles from each other. However, the locations of these plats ordinarily have similar climatic conditions, and some of the tests were over a period of three years.

INFLUENCE OF FERTILIZERS ON THE YIELD OF STRAW, FIBER, AND SEED

Potash in several cases seemed to play a major rôle on these soils. An examination of the data presented in Tables 1 to 4 shows that the inclusion of potash in the fertilizer mixture had a beneficial effect. During all years and on all the different soil types, the phosphorus, sulfur, and potash plats produced more unthreshed straw, more threshed straw, and more fiber than did the plats receiving phosphorus and sulfur but no potash. With one exception the yield of seed was also increased by the application of potash.

As shown by the results in these experiments, very little benefit was obtained from the use of nitrogen in the fertilizer mixture. Com-

parisons between the plats receiving phosphoric acid, sulfur, potash, and nitrogen and those receiving no nitrogen show that in six cases the nitrogen caused an increase in the yield of unthreshed straw and seed, and in three cases it caused a decrease in yield. In five out of nine cases there was an increase in yield of threshed straw. In only three out of nine cases was there an increase in yield of fiber. As the fiber is of much more value than the seed the advisability of applying nitrogen is rather doubtful.

There were no significant differences caused by the application of phosphoric acid. Out of 24 possible comparisons there were 12 cases where additions of P_2O_5 appeared to increase the yields of threshed straw, seed, or fiber, and 12 cases where there were decreases in yields.

In very few cases where sulfur and lime were applied increased yields were obtained. In five tests the application of calcium caused a decrease in the percentage of fiber in the threshed straw. In four cases out of the five the yield of the hackled fiber was lowered when compared with an untreated plat, but the hackling percentage has not been so significantly lowered. The application of a calcium-magnesium lime has usually resulted in an increase in the yield of scutched and hackled fiber and the percentage of fiber in threshed straw.

Almost without exception the percentages of fiber are the highest in plats receiving potash, sulfur, and phosphorus, and in cases where no nitrogen has been added. The yields when greater are not significantly greater when nitrogen has been supplied in addition to phosphorus, sulfur, and potash. This seems to indicate that nitrogen is not especially necessary for these soils as far as fiber yield is concerned. Although the nitrogen did not seem to have any beneficial effect on producing a greater yield of fiber, it did possibly result in a greater seed yield when the average of all the plats is considered. It is very questionable if this increase in seed yield would compensate for the cost of the nitrogen applied and the risk that one might experience in a lowering of the fiber quality. The experiments indicate that the quality of fiber is not materially lowered by the addition of nitrogen; that is, if only the hackling percentages and the fiber strength are judged. In these two latter respects there appeared to be little material difference in the plats receiving nitrogen and those not receiving nitrogen. In conclusion, it can only be said that the use of nitrogen seems to increase slightly the hackling percentages but lowers the fiber strength, but neither of these measurements were significant.

Phosphorus had an indirect effect and showed no significant advantages over the untreated or check plats. However, when phosphorus was present with potash, increased fiber yields were obtained which were due either to potash alone or to a combination of potash and phosphorus.

Although the fertilizers increased the yields on Hillsdale soil from 12 to 30%, the yields did not equal those on unfertilized Brookston soil. The fertilizer applications for fiber flax on Brookston soil differ primarily from those of most other crops in that flax is more responsive to the additions of potash.

SUMMARY

This paper presents results obtained in experiments to ascertain the effect of soil type and fertilizer application on the flax plant in the field.

The heavier types of soil outyielded the lighter soils consistently. Brookston, a heavy soil, gave much greater straw and fiber yield for three years than did Hillsdale, a medium soil. The application of fertilizers to the lighter soils did not cause them to give yields equal to the untreated heavier soils.

Nitrogen added to combinations of potash and phosphorus fertilizers gave no increased fiber yields and only slightly increased seed yields.

Phosphorus alone did not seem to increase the yield of fiber and seed over untreated plats. In combination with potash, increased yields were obtained. This element when applied often resulted in an increased length of straw.

Potash applications when applied with phosphorus resulted in increased yields of fiber and seed.

Calcium, which had been applied to the soil one year before the experiments were started, had only a slightly beneficial effect on yields and lowered the percentage of fiber in the straw. In most cases it also lowered the fiber strength and the hackling percentage, indicating a poorer quality of fiber.

Magnesium when applied with calcium tended to counteract the bad effect produced by the latter element on fiber strength.

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THE OCCURRENCE OF NORMAL (UNPROLIFERATED) FLORETS IN *POA BULBOSA* IN THE UNITED STATES[1]

Morris Halperin[2]

The writer has recently found plants of *Poa bulbosa* L. in California which have normal unproliferated florets, i. e., florets which instead of being transformed into bulbils—the only form thus far described from the Western Hemisphere—contain stamens, including anthers and filaments, and a pistil, including an ovary and two stigmas. The occurrence of the normal form of *Poa bulbosa* in America is thus of sufficient interest to warrant being described.

In the course of field and laboratory studies made in connection with the present report, and as a result of the perusal of the present literature on this species, new data have been acquired concerning (1) the taxonomic characteristics of both the normal and proliferated forms; (2) the ecological conditions under which the two forms occur in the United States; and (3) the agricultural utilization of the proliferated form on the Pacific Coast. These data will be reported separately.

In a brief note on the utility of *Poa bulbosa* for lawns in the South, Piper[3] states, "At Arlington Farm, Va., the grass flowers in April and May, some of the panicles normal, but in many the spikelets are proliferous. At Middleton, Conn., most of the panicles are normal." This is the only report in the literature as to the occurrence of normal spikelets of *Poa bulbosa* in the United States and is not accompanied by any description of the material observed.

In a previous issue of this Journal, Kennedy[4] presented a description and illustrations of normal *Poa bulbosa*. These, however,

[1]Contribution from the Division of Agronomy, Branch of the College of Agriculture, Davis, California. Received for publication January 5, 1931.

[2]Research Assistant. The writer expresses his gratitude for the use of the specimens in the Grass Herbarium of the United States National Museum mentioned in this paper, which were made available to him through the courtesy of Mrs. Agnes Chase of the Herbarium. Professors B. A. Madson and A. W. Sampson, University of California, have been helpful by their critical reading of the manuscript. Special acknowledgment is given to Professor H. E. Malmsten, who independently discovered material of *Poa bulbosa* L. in a locality where its occurrence would otherwise have been unknown, and who obligingly made this material available for the present study.

[3]Piper, C. V. Bulbous bluegrass (*Poa bulbosa* L.). Torreya, 24: 7–8. 1924.

[4]Kennedy, P. B. Proliferation in *Poa bulbosa*. Jour. Amer. Soc. Agron., 21: 80–91. 1929. (Also, the important correction, Jour. Amer. Soc. Agron., 21: 710. 1929.)

refer to European material only. Kennedy, in fact, states, "All the specimens of *Poa bulbosa* found growing in the United States show complete proliferation of the spikelets," being evidently unaware of the above-quoted report by Piper.

NORMAL *POA BULBOSA* IN CALIFORNIA

On May 17, 1930, while on a field trip for the purpose of inspecting natural and artificial plantings of proliferated *Poa bulbosa* in northern California and in southern Oregon, the writer's attention was attracted by a thick growth of unusual-appearing *Poa bulbosa* in the shade of a tree (*Quercus sp.*) near Yreka, Siskiyou County, California.[5] The growth was about 24 inches tall and was associated with no other species, except for a few plants of *Crepis monticola* Coville.[6] A few panicles and several complete green plants of the grass were collected for certain physiological studies to be made on the bulbils.

FIG. 1.—Spikelets of *Poa bulbosa* L. with completely normal florets. American material. x 5.

Subsequent examination of the material in the laboratory revealed the presence in a large number of the panicles of spikelets containing normal florets. The accompanying illustrations taken from this material thus represent the first collection of American specimens of *Poa bulbosa* L. to be illustrated in the literature. Fig. 1 shows a group of completely normal florets, and Fig. 2 a normal spikelet containing a terminal proliferated floret. Fig. 3 shows a normal floret, including the lemma and palea, with the pistil and three stamens between them. No caryopses were found in any of this material.

FIG. 2.—A spikelet of *Poa bulbosa* containing three normal florets and a terminal proliferated floret. American material. x 10.

The next experience with normal *Poa bulbosa* in California occurred at the end of June, 1930, when H. E. Malmsten, Assistant Professor of Forestry, University of California, Berkeley, presented a few panicles of normal *Poa bulbosa*

[5]This locality is approximately 22 miles below the northern boundary of the state, and nearly halfway between the western and eastern boundaries.

[6]Identified by Professor E. B. Babcock, Division of Genetics, University of California, Berkeley, Calif.

collected from plants which had grown on a burned-over area about 11 miles west of Sonora, Tuolumne County, California.[7] Bulbils of proliferated *Poa bulbosa* had been planted there on December 14, 1929, by Professor Malmsten, and the specimens of the normal form were gathered by him on June 22, 1930. Stamens and pistils, but no caryopses, were present. This collection is represented in Fig. 4, which shows a culm terminated by a panicle containing spikelets which either are completely normal or have a proliferated terminal floret with the other florets normal. The proliferated florets are visible as thickened, dark-colored bulbils. Fig. 5 shows a few pistils found in the same material.

FIG. 3.—A normal floret of *Poa bulbosa* showing lemma on the left, palea on the right, and the three stamens and the single pistil between the lemma and palea. American material. x 9.

On July 11, 1930, the writer collected additional, but by then ripe, material of normal *Poa bulbosa* at Montague, about 5 miles distant from the Yreka locality.

On July 15, 1930, a joint inspection with Professor Malmsten of the plats in Tuolumne County showed the plants to be completely mature and dry. Several specimens of the grass growing on three adjacent burned-over areas in that locality were gathered. Examination of this material showed the total absence not only of caryopses but even of stamens and pistils, the flowering structures having evidently withered some time before this inspection was made.

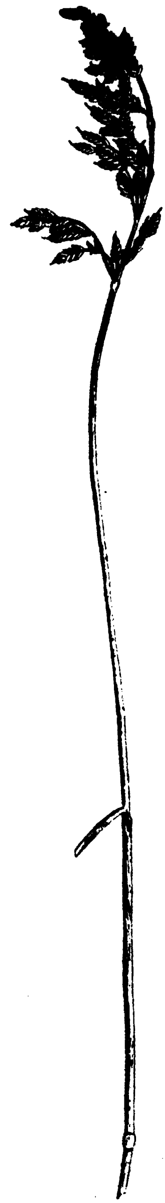

FIG. 4.—Panicle of normal *Poa bulbosa*. The terminal florets in most of the spikelets are proliferated. Am. material. x 1.

[7]This locality is in the eastern part of the state, at approximately the same latitude as San Francisco and more than 400 miles from the Montague locality.

The original material of all these Californian specimens of *Poa bulbosa* L. is in the herbarium of the Division of Agronomy, Branch of the College of Agriculture, Davis, California, and is labelled with the author's collection numbers 301, 303, 307, 308, 311, and 312. Collections 301, 303, and 308 were made by the author; 307 by Professor H. E. Malmsten; and 311 and 312 jointly by Professor Malmsten and the author. Figs. 1, 2, and 3 are from collection 301, and Figs. 4 and 5 from collection 307. The identity of these specimens was confirmed at the Grass Herbarium, United States National

FIG. 5.—A few pistils taken from normal florets of *Poa bulbosa*. The stigmas have either shrivelled or fallen off entirely. American material. x 15.

Museum, Washington, D. C., where duplicates of all the material mentioned above have been deposited for reference. Other sets of duplicates, except for collection 308 and for the portion of collection 307 illustrated in Fig. 5, have been deposited in the Herbarium of the University of California at Berkeley and in the Herbarium of the California Academy of Sciences at San Francisco.

OTHER AMERICAN MATERIAL OF NORMAL *POA BULBOSA*

In October, 1930, access was secured to two specimens in the Grass Herbarium, United States National Museum, Washington, D. C., of *Poa bulbosa* L. grown in the United States. They are as follows:

No. 734248—undated. Material grown by Hillman in the greenhouse (apparently in Washington D. C.).

No. 1389746—May 1928. Material received through Professor B. W. Wells, Raleigh, N. Carolina.

These specimens are discussed elsewhere.[8] H. A. Schoth, Associate Agronomist, U. S. Dept. of Agriculture, Corvallis, Oregon, states in

[8]HAPLERIN, MORRIS. A taxonomic study of *Poa bulbosa* L. Univ. Calif. Pub., Bot., 16: 171–183. 1931.

a personal communication dated December 13, 1930, that he has seen plants of normal *Poa bulbosa* in southern Oregon.[9]

SUMMARY

Plants of *Poa bulbosa* L., i. e., normal *Poa bulbosa*, have been found in several localities in California. Illustrations are presented of the new material.

Heretofore unreported findings of similar material by others in the United States are mentioned here. Other pertinent information regarding the normal form in the United States is also reported in this study. The present report is thus a complete account of all the data available at present as to the occurrence of *Poa bulbosa* L. in the Western Hemisphere.

Agrostologic and ecologic data regarding both the normal and the proliferated forms of *Poa bulbosa*, and economic data regarding the latter, are being reported separately.

[9]After this paper was submitted for publication, the writer, while on a visit to the Oregon Experiment Station at Corvallis, was shown by Mr. Schoth a small experimental planting of normal *Poa bulbosa*. Mr. Schoth stated that this planting had been under his observation since 1916. This heretofore unreported observation would thus constitute the earliest observation, in the knowledge of the writer, of normal *Poa bulbosa* in western America. Specimens were collected at the time of the visit on April 28, 1931.

THE EFFECT OF UNIFORMITY OF SPACING SEED ON THE DEVELOPMENT AND YIELD OF BARLEY[1]

H. B. SPRAGUE and N. F. FARRIS[2]

For the past 25 years investigations have been conducted throughout the United States by numerous workers to determine the optimum quantity of seed required for a given area of land. The large number of separate tests conducted on the problem are ample evidence of a general understanding that the optimum rate of seeding for any crop varies both with the characteristics of the crop (and variety) and the environment in which it is grown. Obviously, the ultimate goal is the complete utilization of the environment by the crop in question, using final yield as the index of that utilization.

In general, the reports of experiments on rates of seeding of small grains for the various regions of the country have indicated that there is a rather definite limit beyond which heavier seeding rates fail to produce increases in yield of crop. Thus, Thatcher (11)[3] has reported the results of continuous tests for 22 years on seeding rates and average yields of winter wheat in Ohio as follows: 3-peck rate, 25.7 bushels per acre; 4-peck rate, 27.3 bushels; 5-peck rate, 27.8 bushels; 6-peck rate, 28.3 bushels; 7-peck rate, 28.3 bushels; 8-peck rate, 29.1 bushels; 9-peck rate, 28.9 bushels, and 10-peck rate, 28.5 bushels.

Under humid conditions, the quantity of seed planted per acre for spring grains, such as barley, usually is larger because of reduced opportunity for tillering, but the principle is similar to that noted for wheat. For example, four years of testing spring barley in Ontario gave the following yields: for 6 pecks of seed, 47.8 bushels; for 8 pecks, 50.3 bushels; and for 10 pecks, 48.5 bushels. It is apparent from these data, which may be taken as representative of that secured with small grains by other workers, that there is no advantage in increasing the average number of plants per unit of area beyond a certain definite limit. The limit itself is determined by the conditions of soil and climate and the characteristics of the crop, but in all cases it represents a condition where the soil and atmosphere are being utilized as completely as possible by the particular variety of the crop planted.

[1]Contribution from the Department of Agronomy, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Received for publication January 17, 1931.

[2]Agronomist and Research Assistant in Agronomy, respectively.

[3]Reference by number is to "Literature Cited," p. 533.

It is well known that the seeding of grains on farms is never carried out in such a manner that the seed is regularly and evenly spaced over the entire field or any considerable portion of it. Excessive irregularity in distribution of plants is no doubt responsible for reduction in yields, and the increase in production from drilled grain as compared with that broadcast may be due in part to the better distribution of seed from drilling. Very few studies have been conducted to determine whether increasing the regularity of spacing seed in drill-planted small grains has any relation to yields produced. Engledow and his associates (2, 3, 4, 5) have investigated this problem under English conditions and have noted great variation in the density of plant populations in drilled wheat. Moreover, Engledow observed a definite relation between density of population of the various portions of the drill row and the yields of grain and straw produced. The degree to which enhanced tillering compensated for the small number of plants present on sparsely populated sections was found to be less than supposed, since 30% of the crop was produced by plants having only one head each. From these studies, Engledow concludes that the average number of plants per foot of drill row is a valueless abstraction, and that yields per acre are determined to a large extent by the uniformity with which the seed is spaced in the row.

Studies by Engledow and Wadham (2) indicated that tillering changes are sensitive to variations in spacing, but that varieties differ greatly in their response to the space available. The fluctuations in density of plant populations were found to depend on the mechanical efficiency of the drill for even distribution of seed (5), on the influence of the soil tilth on drill action, and on the loss of plants through unfavorable weather, diseases, and animal pests. However, the number of seed deposited in a given section of drill row was considered the primary cause of fluctuations in plant density. The possibility that soil variation was responsible for much of the effect on yields of individual drill row sections rather than population density was excluded by Doughty and Engledow (6) after special consideration of this phase of the problem.

If yields per acre are greatly influenced by uniformity of spacing of plants in the drill row, considerable attention should be given to the matter, since it is well known that population density fluctuates greatly in consecutive sections of the drill row. It has been the custom in agronomic experiments to deal with average quantities of seed per acre and to assume that relatively large fluctuations in population density might occur without greatly influencing the

yield produced. The work of Engledow and associates, if applicable to conditions in America, would necessitate a resurvey of all experiments on rate of planting for cereals.

There is some question, however, regarding the true significance of fluctuations in number of plants in successive units of the drill row. It seems possible that those areas with insufficient plants to utilize the soil resources completely might reasonably be expected to be utilized partially by roots of plants in nearby sections where the number of plants is considerably greater. This type of compensation for irregularity of stand has been investigated by Kiesselbach (7) for corn. Thus, 3-plant hills adjacent to one hill with 2 plants yielded 102% of normal; adjacent to one hill with 1 plant, 109%; and adjacent to one blank hill, 115%. Also, hills with only 1 plant but surrounded by normal stand hills yielded 50% of normal, and those with 2 plants, 82% of normal. On the basis of these data, at least 85% of a normal yield was obtained in spite of the loss of 2 plants from a hill of corn, and the remaining 15% may have been largely made up by increased growth of plants in the second hills distant.

It is obvious that the corn plant is capable of considerable adjustment in root development which permits fairly adequate utilization of the soil in spite of irregularity of stand. Additional evidence on this point is given by Kiesselbach (8) regarding the effect of an uneven stand where the average number of plants per acre remained the same. With a uniform distribution of 3 plants per hill, the yield per acre was 59.0 bushels of grain; alternating 2 and 4 plants, 59.2 bushels; alternating 1, 3, and 5 plants, 56.0 bushels; and alternating 1, 2, 3, 4, and 5 plants, 58.6 bushels. Even when the average quantity of seed planted per acre varies markedly, considerable plant adjustment takes place. Kiesselbach (8) reports that with 7,112 plants per acre, the yield of corn was 49.4 bushels and with 14,224 plants, 50.7 bushels.

In the case of winter wheat, Kiesselbach and Sprague (9) have shown the manner in which such adjustment is made. When 3 pecks of seed were sown the average number of mature plants in 10 feet of drill row was 94; for 5 pecks of seed, 146 plants; and for 8 pecks, 229 plants. The number of fertile spikes per plant was 3.5, 2.7, and 1.8 for the 3-, 5-, and 8-peck rates of seeding, respectively. The number of grains per spike was 17.1 for the 3-peck rate, 15.9 for the 5-peck rate, and 14.2 for the 8-peck rate. The average weight of the individual grains was 0.027, 0.024, and 0.023 gram for the 3-, 5-, and 8-peck rates, respectively. It is obvious, from these data,

that the final yield was largely determined by the soil conditions rather than by density of population.

In view of the statements made by Engledow and associates that the *average* density of plants in the drill row is of scant importance as compared with regularity of spacing and that yields of wheat are very greatly influenced by the regularity of spacing within each unit of the row, it seems desirable to examine the question with particular reference to American conditions. It is plausible to assume that marked variations in number of plants per unit of drill row may occur, with the attendant variations in yield of each unit, without any reduction in yields per acre. However, this is possible only if the plants in well-populated sections adjoining the thinly-populated ones extend their root systems sufficiently to utilize thoroughly all of the soil resources. If this condition exists, the significant data on yields may be found in the averages for several to many units of the drill row.

EXPERIMENTAL PROCEDURE

Studies were undertaken during the season of 1929 to determine the effect of spacing seed on the development and final yield of barley. The crop was planted in two ways, *viz.*, with seed uniformly spaced in all sections of the rows, and with variable quantities of seed in successive sections but having an average rate of seeding equal to that of the rows with uniformly spaced seed. An experiment of this type should reveal the true significance of regular plant spacing as a factor in yields per acre. Since Brenchley and Jackson (1) have reported a scanty development of the root system for barley as compared with wheat, barley was selected as a suitable crop for testing the ability of the plants to extend their root systems sufficiently to utilize fully the soil resources with irregular spacing of plants. If average yields are affected by the uniformity of spacing the seed, this relation should be more readily detected with barley than with wheat.

The experiment was conducted on a small field of sandy loam soil which appeared quite uniform in character of the plow zone. This soil is underlaid by a gravelly clay horizon at a depth of 18 inches, and grades into a coarse sand below this horizon. Planting occurred on April 19 to 21, after a 4-12-4 fertilizer had been broadcast at the rate of 400 pounds to the acre and well mixed with the surface soil. The field was in good tilth at the time of planting and a satisfactory stand of plants was obtained.

The uniform rate of seeding was 10 pecks to the acre, which is an optimum quantity of seed for this region in normal seasons. The four variable rates were 6, 9, 11, and 14 pecks of seed per acre; the average of the four being 10 pecks, equivalent to the uniform rate. The seed was planted in 1-foot sections in rows 16 feet long and 8 inches apart. Each foot section was labeled with the plat number and the rate of planting, as shown in Fig. 1. Three rows of the uniform rate of seeding were alternated with three of the variable rate throughout the field. In all, there were 480 foot sections planted at the uniform rate and an equal number at the variable rate. A random distri-

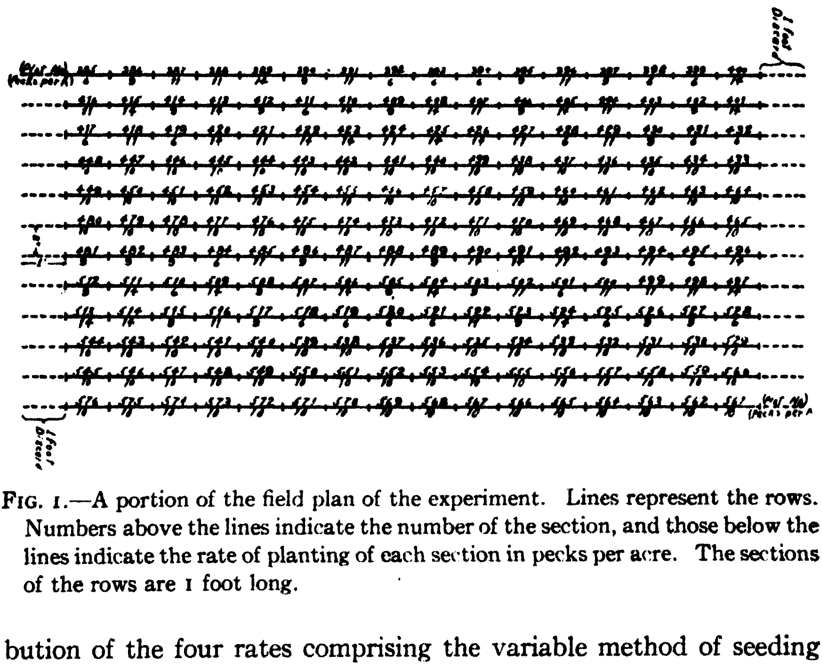

FIG. 1.—A portion of the field plan of the experiment. Lines represent the rows. Numbers above the lines indicate the number of the section, and those below the lines indicate the rate of planting of each section in pecks per acre. The sections of the rows are 1 foot long.

bution of the four rates comprising the variable method of seeding was obtained for successive sections of the row by drawing colored balls from a container, each color representing a different seeding rate.

The variety chosen for the test was Alpha, a pure-line selection which has yielded well in this region (10). The average weight per kernel was found to be 40 milligrams, and accordingly, the number of seeds per foot of drill row was as follows: for 6 pecks of seed to the acre, 13 grains per foot section; for 9 pecks, 19 grains; for 10 pecks, 21 grains; for 11 pecks, 23 grains; and for 14 pecks, 29 grains.

Observations on the crop were confined to the center rows of the 3-row plats, since various workers have reported competition between the border rows of unlike treatments. By choosing only the center

rows, each section for which data were obtained was surrounded by the same method of planting, whether uniform or variable.

The root systems of plants at different spacings were observed on July 5 and 6, using the method described by Weaver (12). The crop was harvested on July 15 and 16, and yielded approximately 22 bushels of grain per acre. The rainfall during the growth period was about 14 inches, but a moisture deficiency in late June and early July affected growth adversely. No injury from disease, insect pests, birds, or other pests was observed during the growing season or at harvest. The center rows only were harvested from each 3-row plat and the first and last foot sections in these rows were discarded, leaving 140 sections of the rows for study with each of the two methods of seeding. Because of the random distribution of the seeding rates comprising the variable method, the number of foot sections harvested for each of the component rates of seeding were not equally numerous. Twenty-six sections of the 6-peck rate were harvested, 36 of the 9-peck rate, 42 of the 11-peck rate, and 36 of the 14-peck rate. The average rate of seeding for the harvested sections of the variable seeding was therefore 10.33 pecks per acre, as compared with 10.0 pecks for the uniform rate.

The plants in each foot section were uprooted, tied together, and labeled. After air-drying, the number of plants was determined and the culms were cut at the soil line. The number of both fertile and sterile culms was observed and the length of the fertile culms was taken, measuring from the cut ends to the first node on the rachis. Length of spike included both sterile and fertile portions, but not the awns. The number of kernels was counted on each spike, and the total number for the foot section was used to calculate the average weight per kernel. Yields of straw from fertile and sterile culms were obtained for each section, as well as yield of threshed grain.

RESULTS

EFFECT OF RATE OF PLANTING ON PLANT DEVELOPMENT

The effect of population density on plant and tiller development is shown in Table 1. The percentage of seeds which produced shoots was 80.8 for the 6-peck rate, 79.5 for the 9-peck rate, 82.2 for the 11-peck rate, and 81.7 for the 14-peck rate, indicating little relation between spacing of seed and emergence of plants. However, a clear relation was found to exist between thickness of seeding and the percentage of plants which produced grain. The percentages were 74.3, 67.5, 64.6, and 55.3 for the 6-, 9-, 11-, and 14-peck rates of seeding, respectively.

The total number of fertile culms per foot section was obviously greater for the heavier rates of seeding, but the number of fertile culms per plant was inversely correlated with population density. An inverse correlation was also noted between number of plants per foot section and (a) length of fertile culms, (b) length of spike, and (c) number of grains per spike. The average weight per grain was not significantly modified by the rate of seeding, whereas the total number of kernels per foot section increased with the quantity of seed planted and the number of fertile culms produced. It is apparent that considerable adjustment has been made in response to space available for development of individual plants. In spite of a progressive increase in number of kernels per section accompanying increases in the seeding rate, there was no increase in grain yield with more than 11 pecks of seed.

TABLE 1.—*Effect of thickness of seeding on the development of barley plants when the amount of seed varies at random in consecutive 1-foot sections of the row.**

Character	Quantities of seed per acre			
	6 pecks	9 pecks	11 pecks	14 pecks
Number of seeds planted per foot of row	13	19	23	29
Number of seeds germinated	10.5	15.1	18.9	23.7
Percentage of seeds germinated	80.8	79.5	82.2	81.7
Number of plants matured	7.8	10.2	12.2	13.1
Percentage of plants matured	74.3	67.5	64.6	55.3
Number of fertile culms per foot of row	9.9	12.4	13.5	14.4
Number of fertile culms per plant	1.27	1.22	1.11	1.10
Length of fertile culms, cm	48.7	47.4	47.4	47.1
Length of spike, cm	8.2	7.8	7.7	7.5
Total number of kernels per foot of row	205.9	245.5	264.6	·273.6
Number of kernels per spike	20.8	19.8	19.6	19.0
Weight per kernel, mgm	30.0	30.3	30.7	29.7
Yield of kernels per foot, grams	6.18	7.44	8.12	8.13
Yield of straw from fertile culms, grams	6.70	8.06	8.74	8.73
Total yield of fertile culms, grams	12.88	15.50	16.86	16.86
Number of sterile culms per foot of row	4.4	7.1	8.1	10.5
Weight of sterile culms, grams	2.13	3.63	4.16	5.41
Total yield of dry matter per foot of row, grams	15.01	19.13	21.02	22.27

*The figures are averages per foot section of the row in every case.

The principal adjustment between number of plants and the space available for each occurred in the number of fertile culms per foot of row. An increase of 133% in the seeding rate was accompanied by an increase of only 45.4% in number of fertile culms. Apparently, the number of culms producing grain was largely controlled by soil conditions. Moreover, the fertile culms had fewer kernels per spike at the heavier rates of seeding, a further adjustment within the plant in response to soil resources available. If 11 pecks be taken

as the optimum rate of seeding, 6 pecks is but 54.5% of the optimum. However, the 6-peck rate of seeding actually produced 76.1% as much grain as the 11-peck rate instead of 54.5%, an indication of the crop's ability to increase its activities in response to the soil resources available.

Much the same relation exists with regard to yield of straw from fertile culms as for grain. However, when the yield of straw from sterile culms is included, the yields of total dry matter increased with the quantity of seed sown, although not proportionately. From a practical standpoint, grain is far more important than straw and the conclusion may be drawn that no advantage was derived from the planting of more than 11 pecks of seed under these conditions. It seems probable that a system of planting in which the seeding rates were 6, 9, 11, and 11 pecks per acre, occurring in random fashion in successive sections of the row, would have yielded fully as much grain as the system of 6, 9, 11, and 14 pecks which was actually used. With a more favorable growing season, the inclusion of the 14-peck rate might have increased yields appreciably.

COMPARISON OF UNIFORM AND VARIABLE METHODS OF SEEDING

Whatever relation exists between yields of various foot sections of the row and the variations in numbers of plants, the critical question is whether or not the average yield from a variable system of planting equals that of a system in which there is a uniform or constant spacing of seed throughout. A detailed comparison of average plant development and yields per foot of row for both methods of seeding is given in Table 2. Considering first the grain yields, it will be noted that the variable method produced 5.5% more grain than the uniform rate. This was primarily due to the increased number of fertile spikes produced per plant with the variable system. As noted in the foregoing, the average rate of seeding for the variable method was 10.33 pecks per acre as compared with 10.0 pecks for the uniform method. Since this difference of 3.3% in quantity of seed was accompanied by an increase of 5.5% in yield, it seems probable that 10 pecks of seed were not quite sufficient to insure full utilization of the soil resources available in 1929. There is no evidence that the variable method of seeding is superior to the uniform system, but, on the other hand, it is obviously not inferior. Under the conditions imposed in this experiment, the crop was fully as able to utilize the environment with irregular spacing of seed as with regular spacing. The same relation exists for straw yields and total yields of dry matter as for grain yields.

TABLE 2.—*The effect of constant and variable amounts of seed per foot of row on the development of barley plants when the average quantity of seed planted is nearly the same for both methods of planting.*

Character	Averages per foot of row for		Variable rate in percentage of uniform rate
	Variable rate of seeding (6, 9, 11, and 14 pecks)	Uniform rate of seeding (10 pecks)	
Seeding rate (pecks per acre)	10.33	10.0	103.3
Number of seeds planted per foot of row	21.7	21.0	103.3
Number of seeds germinated	17.6	17.1	102.9
Percentage of seeds germinated	81.1	81.4	99.6
Number of plants matured	11.1	11.1	100.0
Percentage of plants matured	63.1	64.9	97.2
Number of fertile culms per foot of row	12.8	12.1	105.8
Number of fertile culms per plant	1.15	1.09	105.5
Length of fertile culms, cm	47.6	48.1	99.0
Length of spike, cm	7.8	7.8	100.0
Total number of kernels per foot of row	252.2	238.4	105.8
Number of kernels per spike	19.7	19.7	100.0
Weight per kernel, mgm	30.2	30.3	99.7
Yield of kernels per foot of row, grams	7.6	7.2	105.5
Yield of straw from fertile culms, grams	8.2	7.8	105.1
Total yield of fertile culms, grams	15.8	15.0	105.3
Number of sterile culms per foot of row	7.8	7.6	102.6
Weight of sterile culms, grams	7.5	3.9	192.3
Total yield of dry matter per foot of row, grams	23.3	18.9	123.3

Since it has been noted in the foregoing that sparsely populated sections are only partially capable of increasing in size in order to compensate fully for the smaller number of plants present, the balance of the adjustment necessary for full yields must have been accomplished by the surrounding foot sections. There are at least two ways of determining the actual existence of such a condition; one, by correlating grain yields of the several foot sections with the average quantity of seed planted in the four sections at the sides and ends of each section; and second, by examining the root systems. The correlation coefficient determined for the grain yields of the 26 foot sections planted at the 6-peck rate and the average planting rate of the surrounding sections was +0.109 ±.131; for 36 sections of the 9-peck rate, —0.421 ±.093; for 42 sections of the 11-peck rate, —0.617 ±.064; and for 36 sections of the 14-peck rate, +0.066 ±.112.

With the 6-peck rate of seeding, the population was apparently so small that the plants were always able to develop to the fullest

extent compatible with the level of productivity for this soil, and the density of plants in surrounding sections therefore had little or no effect on grain yield. Significant negative correlation coefficients were obtained for the 9- and 11-peck rates of seeding, indicating that yields were reduced when the average rate of seeding in the surrounding sections was greater, and augmented when the population density of surrounding areas was reduced.

Since the 14-peck rate of seeding was the heaviest one used, it would be expected that plants in sections seeded at this rate would always encroach on the soil volumes of surrounding sections. The correlation coefficient of +.066 between grain yields of the 14-peck sections and the average rate of seeding in surrounding sections indicates that the utilization of soil resources in adjacent areas by the thick planting was not expressed in grain production. However, a correlation of —.238 ±.106 between yields of dry matter from sterile culms and the average rate of seeding in surrounding sections shows that encroachment of the thickly-planted sections on those of adjacent areas increased as the population density of the adjacent sections decreased. The failure of these culms to produce grain may be attributed to the very close spacing of seed which reduced the early vigor and rate of growth of the individual plants and enforced a comparatively late occupation of soil in the adjacent, less thickly populated sections. The unusual moisture deficiency of late June and early July probably prevented the tillers formed as a result of such late occupation from normal development into grain-producing culms.

VARIABILITY IN YIELDS

The variation in grain yields of foot sections is most interesting since it calls attention to the great importance of soil variability in determining yields as compared with the factor of seed distribution. A detailed comparison of this variability is given in Table 3. In spite of the fact that the variable method of seeding included rates varying 40% in both directions from the mean, the coefficient of variation for grain yields of this method was only slightly greater than for the uniform method of seeding, not enough to be statistically significant. Evidently, the supply of nutrients, moisture, degree of aeration, etc., of the soil largely determined the yield of crop produced on the individual foot sections, and the quantity of seed planted had relatively small effect.

Taken individually, the four seeding rates which made up the variable method had coefficients of variability for grain yield not greatly different from that of the uniform method. The 14-peck rate

TABLE 3.—*Mean yields of grain and coefficients of variation for the various systems and rates of planting.*

Seeding methods and rates	Mean yield of grain in grams per foot of drill row	Probable error of mean*	Coefficient of variation for grain yields	Probable error of C.V.†
			%	%
Uniform method of seeding (10 pecks per acre)	7.2	±.12	28.8	±1.25
Variable method of seeding (average 10.33 pecks, per acre)	7.6	±.14	33.0	±1.47
Variable seeding rates:				
6 pecks	6.18	±.23	27.3	±2.74
9 pecks	7.44	±.23	27.1	±2.31
11 pecks	8.12	±.27	31.9	±2.58
14 pecks	8.13	±.33	36.2	±3.24

*P. E. of mean calculated by the formula, $E_M = \frac{\pm 0.6745\, \sigma}{\sqrt{N}}$.

†P. E. of coefficient of variation calculated by the formula, $E_V = \frac{\pm 0.6745 \times V}{\sqrt{2N}} \left[1 + 2\frac{(V)^2}{(100)}\right]^{1/2}$

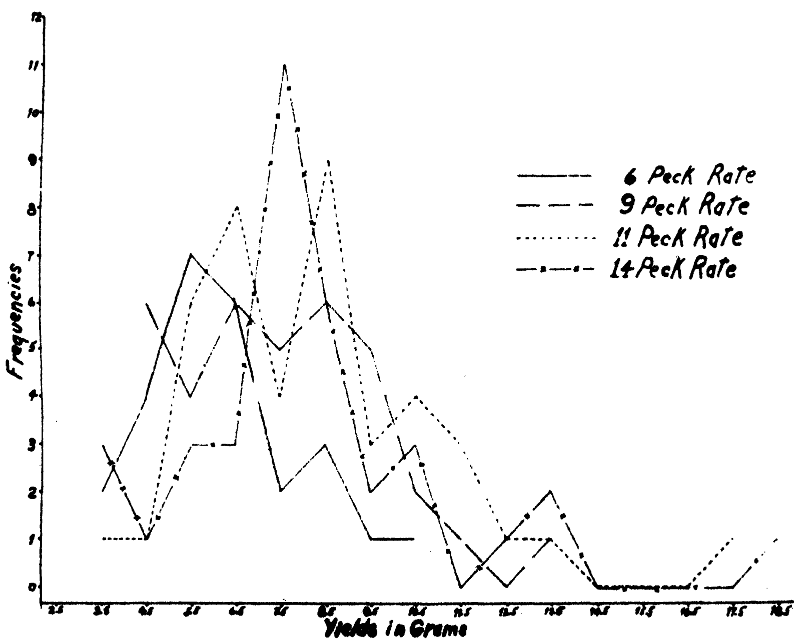

FIG. 2.—The distribution of grain yields per section of row for the different rates of planting making up the variable rate.

of seeding was distinctly more variable in grain than the other rates of seeding as a result of the failure of many culms to produce seed. This situation is clearly shown by a coefficient of variation of 24.4% for the total yield of dry matter for the 14-peck sections.

The distribution of grain yields per section of row for each of the rates making up the variable method of seeding is shown in Fig. 2. The total range increased with the quantity of seed sown as follows. For the 6-peck rate, 3.5 to 10.5 grams of grain per foot, for the 9-

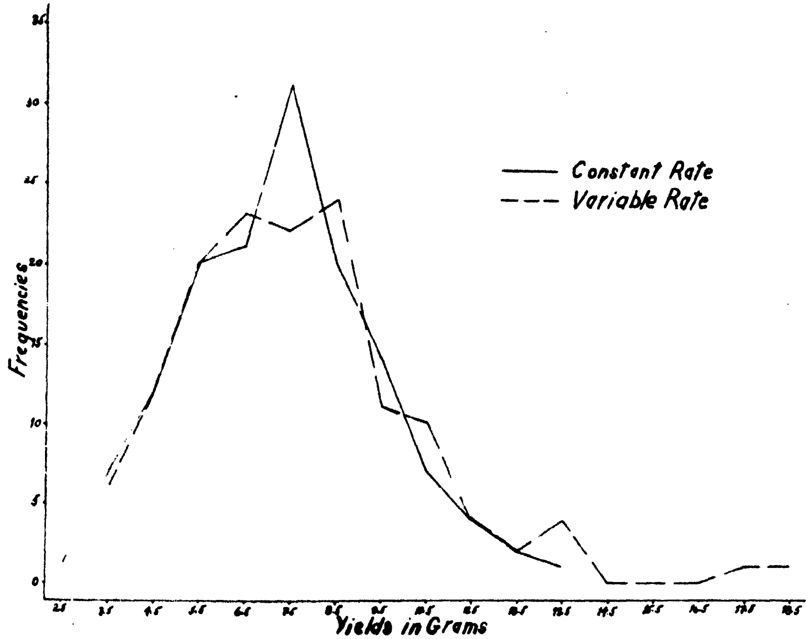

FIG. 3.—The distribution of grain yields per section of row for both the constant and variable methods of planting.

peck rate, 4.5 to 13.5 grams; for the 11-peck rate, 3.5 to 17.5 grams; and for the 14-peck rate, 3.5 to 18.5 grams. It is evident that yields of grain fluctuated widely for each rate of planting. Although the higher yields of certain sections planted at thicker rates might be ascribed to the population density, the low yields of other sections planted at the same rates indicate that soil variation is probably a more important factor than thickness of planting.

Further proof of this relationship between soil conditions and grain yield is found in Fig. 3, showing the distribution of grain yields per section of row for 140 plats each of the variable and uniform methods of planting. Not only is the range in yields very similar for both methods of planting, but the frequencies for each class of

yields are very nearly identical. Obviously, variations in spacing of plants as great as 40% of the mean had little effect on grain yields; and the variability observed was primarily caused by soil conditions.

ROOT DEVELOPMENT

The examination of root systems of plants grown in sections with various rates of planting was made on July 5 and 6, approximately

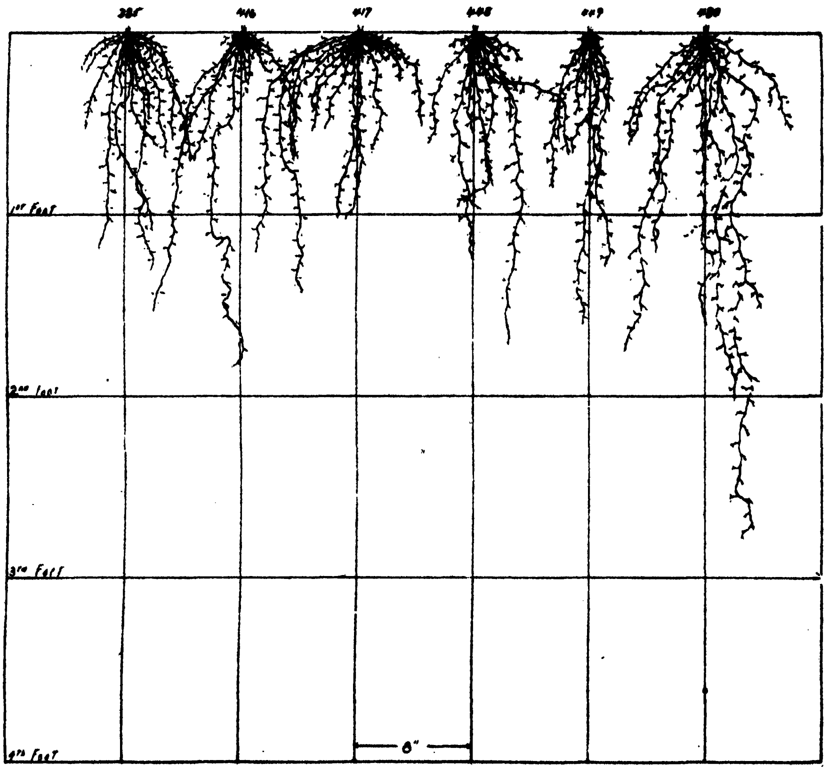

FIG. 4.—Showing the root development of plants in sections of the row planted at various rates. Only one plant in each section is shown. Plats 385 and 417, 6 pecks per acre; plats 448, 449, and 480, 10 pecks; and plat 416, 11 pecks.

one week before the crop was physiologically mature. Root tracings for the main roots of one normal plant in each of 12 contiguous sections are shown in Figs. 4 and 5. The method adopted was as follows: A trench was dug at right angles to the rows, exposing the sections to be examined; after which the soil was carefully removed from the roots of the plants selected for study with a small hand pick. The exposed roots were drawn on cross-section paper in the field, and later plotted to scale on a chart. The soil was hard and

dry at the time the roots were examined and considerable difficulty was experienced in tracing the finer roots and the extremities of the principal roots. However, all of the more important roots of each plant are shown in the figures; and since adjacent foot sections located in a typical portion of the experimental field were selected for study, the root systems may be compared satisfactorily.

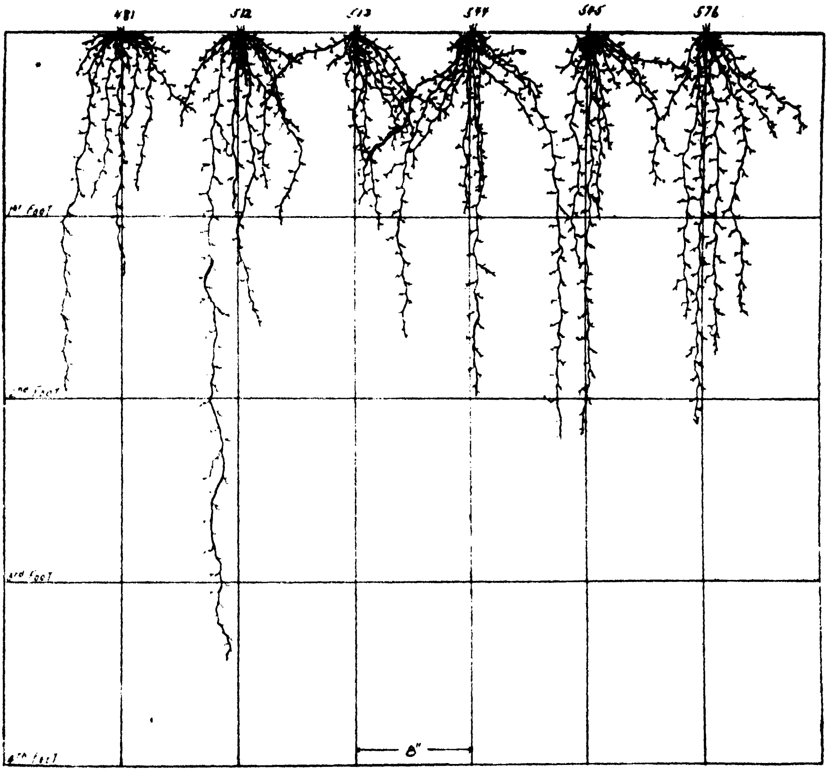

FIG. 5.—Showing the root development of plants in sections of the row planted at various rates. Only one plant in each section is shown. Plats 481 and 512, 9 pecks per acre; plats 544, 545, and 576, 10 pecks; and plat 513, 14 pecks

An approximation of the degree of development of the individual root systems may be obtained by counting the number of main roots of each plant. A comparison on this basis is given in Table 4.

For the plants examined, those in thickly-planted sections showed somewhat less vigorous development of roots than plants having more space, indicating an adjustment of plant growth in response to the available soil resources for the plant in question. Since complete utilization of the soil depends on both the development of individual root systems and the number of plants for the soil volume

concerned, the greater development of root system for single plants on thinly planted areas is not indicative of more complete occupation of the soil than for thickly planted sections. It is fairly obvious however, that increased development of the tops of individual plants is associated with a corresponding development of the root

TABLE 4.—*Rate of planting barley and the number of main roots found on single plants.*

Plat No.	Seeding rate, pecks per acre	Number of main roots on a single plant
385	6	13
416	11	10
417	6	15
448	10	12
449	10	9
480	10	10
481	9	12
512	9	13
513	14	9
544	10	12
545	10	10
576	10	8

system. Therefore, any study of plant development must recognize the influence of root development and activity on top growth, and the fact that root systems may not be confined to the same vertical zone as that occupied by the aerial portions of the plant. This being the case, any system of planting barley and similar crops which makes full use of the soils' resources may be expected to yield the maximum quantity of grain, in spite of wide variations in the distribution of fertile culms on the surface area of the field. The most reliable measure of the value of a system of planting showing such variation may be obtained by averaging data from samples of the crop drawn from the field in such manner that a fair representation is had.

The root tracings as a whole indicate a rather scanty development of the barley root system, which is in accord with the findings of Brenchley and Jackson (1). In general, the roots tend to grow downward with a limited lateral spread. Very few roots penetrated the compact gravelly clay horizon which occurred at a depth of about 18 inches, but those which were able to push through showed considerable development in the sandy horizon beneath. Since Weaver (12) and Brenchley and Jackson (1) have both reported a more extensive root system for wheat than for barley, the results obtained with barley in these experiments may be expected to apply to wheat also.

Weaver (12) also noted a greater development of roots for oats and rye than for barley on soils of the middle west and great plains. If these root relations are found to exist on other soil groups, oats, wheat, and rye may be assumed to have the ability of increasing root development sufficiently to make complete use of the soil in spite of rather irregular spacing of seed. This experiment has shown that seeding rates of barley may fluctuate 40% from the average without reducing yields of grain. With the more extensive root systems of wheat, rye, and oats, even wider fluctuations in seeding rate should not reduce the yields.

American grain drills, when functioning normally, may be assumed to distribute seed of small grains satisfactorily so far as total yield of crop produced is concerned, and experiments reported on the optimum seeding rates for specific crops and varieties in various regions may be accepted at values commensurate to the degree with which they fairly sampled the variable complex of soil and climate.

The results likewise indicate that the typical development of a variety may be determined in the field quite as satisfactorily from stands showing considerable irregularity in spacing of plants as from stands with plants carefully spaced, providing the average rate of seeding is equal in the two systems. In either case, it will be necessary to observe a comparatively large number of units from the rows to insure a satisfactory sampling of soil variability. Field comparisons of varieties of the same crop from the standpoint of grain yields or of individual characteristics of the plants should also be possible with ordinary drill planting, if due regard is paid to the laws of sampling.

SUMMARY

During the season of 1929, studies were conducted with barley under field conditions to determine the relation between uniformity of spacing seed and development and yield of the crop. Information on this relation under American conditions was specially desired because of the observations of Engledow and his associates that yields of wheat fields in England were greatly influenced by the regularity of spacing seed. Two methods of planting were adopted in this study. In one, seed was planted in such manner that each foot of row received kernels evenly spaced and equivalent in number to a seeding rate of 10 pecks per acre, this being termed the uniform method. In the second, or variable, method, the average rate of seeding was 10 pecks per acre, but consecutive sections of the row

were planted at different rates, equivalent to 6, 9, 11, and 14 pecks of seed to the acre, and a random distribution of the four rates was provided. Three rows of each method of seeding alternated throughout the test field, and observations were confined to the center rows to eliminate competition between unlike methods of seeding. A total of 140 foot sections of row were harvested from each of the uniform and variable methods of planting, and a detailed comparison was made of plant development and yield.

Yields of grain and straw increased with the seeding rate when the component rates of the variable method were considered. However, the increase in yield was far from proportional to population density, because of the reduced development for individual plants at the closer spacings. The data indicate that the barley plant has considerable ability to modify its development in response to the soil resources available.

The average yield of grain from the variable method of seeding was slightly greater than for the uniform method. No reduction in average straw yields resulted from irregularity of stand. Correlation coefficients between yield of grain for each foot section and the average rate of seeding of surrounding sections indicated that thickly populated areas draw on the soil resources of neighboring sparsely populated areas. The balance of the adjustment necessary for normal yields was brought about by increased development of individual plants in thin stands.

Root studies indicated that root systems of this crop were not confined to the vertical zone occupied by the aerial portions, and that top growth of individual plants was correlated with root development. The conclusion is drawn that crops, such as oats, wheat, and rye, which are reported to develop more extensive root systems than barley, are probably even more capable of completely utilizing the soil resources in spite of considerable irregularity of stand.

The variability of the soil was found to be a far more important factor in determining yields of units of the planted row than population density. Mean values of individual plant characters were not appreciably changed by the irregularity of spacing seed, nor was the reliability of the mean values significantly affected. Because of soil variation, a comparatively large number of samples of the crop will be required to represent fairly conditions in the field being examined.

American grain drills, when functioning normally, may be assumed to distribute seed of small grains satisfactorily so far as total yield of crop is concerned. The factor of regularity in spacing seed

may be largely ignored in conducting rate-of-seeding tests, even though the variation in seeding rate varies as much as 40% from the mean in consecutive sections of the row.

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INBREEDING WITH PARTICULAR REFERENCE TO MAIZE[1]

R. J. GARBER[2]

Inbreeding was practiced consciously or unconsciously long before the era of modern genetics. It is perhaps true that all improved varieties of plants not asexually reproduced and all improved breeds of livestock originated through some degree of inbreeding. The pioneer breeders of plants and animals sought to establish and "fix" certain types by controlled crosses and selection. Hence they were more or less unconsciously practicing inbreeding. Even in those cases where the hand of man did not aid nature in fixing types, some inbreeding must have taken place, or at least some form of breeding which led to the same result, namely, the establishment of a certain degree of homozygosity for those characters which permitted the species to thrive in a given environment.

Unfortunately, the results of the earlier attempts at inbreeding were misinterpreted. It was observed that close breeding apparently had a deleterious effect on the offspring and consequently the idea that inbreeding was injurious *per se* became rather generally accepted. There is still considerable superstition and misinformation regarding this practice, even though geneticists during the past 30 years have established rather definitely the significance and interpretation of inbreeding. The investigations and the hypotheses formulated in the explanation of hybrid vigor have been very helpful in a better understanding of the genetics of inbreeding.

Most plant geneticists are of the opinion that hybrid vigor in maize is a manifestation of a large number of favorable growth factors which are in some degree dominant over unfavorable ones, and this, together with linkage, makes it extremely difficult, if not impossible, to bring together as many different favorable growth factors in the homozygous condition as it is in the heterozygous condition. Yield of grain may be used as one index of hybrid vigor. Many attempts have been made to increase the yield of maize by the ear-to-row method since it was introduced by the Illinois Experiment Station late in the nineteenth century. Several experiments have shown some increase in yield as the result of a single mass selection

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Presented before the geneticists interested in agriculture and the joint geneticist section of the A. A. A. S. at Cleveland, Ohio, December 29, 1930. Published with the approval of the Director of the Experiment Station as Scientific Paper No. 96. Received for publication January 22, 1931.

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by the ear-to-row method, but no experiment has shown a significant progressive increase in yield as the result of continuous ear-to-row breeding. Is it not possible that this method reaches its maximum effectiveness through the selection of individuals having a maximum number of different factors favorable to yield the first year it is practiced?

Some time ago the yielding ability of a first generation cross between Clarage, a yellow dent variety, and Longfellow flint was determined in comparison with the parental varieties for a period of 3 years and at two different localities in West Virginia. The first generation cross yielded significantly more grain than did Clarage, the higher yielding parent. The question arose whether the first generation cross would yield more than the parent varieties if the latter were first subjected to an ear-to-row test. To answer this question, 200 ears of each variety were grown in duplicate in an ear-to-row experiment. On the basis of this test the highest yielding ears of each variety were determined. Part of the remnants of the higher yielding ears of Clarage were planted in alternate rows with part of the remnants of the higher yielding ears of Longfellow, to obtain the crossed seed. The yielding ability of this crossed seed in comparison with that of the remnants from both parent varieties was determined in replicated plats. During both of the years when the comparison was made the remnant seed from the highest yielding Clarage ears gave somewhat greater yields than did the first generation cross. These results seem to indicate that the single mass selection by the ear-to-row method was as effective in discovering combinations of genetic factors favorable to yield in the Clarage variety as was hybridization between Clarage and Longfellow in bringing together favorable combinations. Ear-to-row breeding, however, cannot be considered a very close form of inbreeding.

Inbreeding experiments with maize were initiated independently by East and by Shull about 25 years ago. Since that time most of the trained plant breeders interested in the improvement of this crop have followed methods similar to those used by these earlier investigators. Briefly, the method consists of establishing and studying the behavior of lines produced by self pollination—the most intensive form of inbreeding known.

In this paper an attempt will be made to discuss very briefly the methods of inbreeding maize which have been followed rather generally by the technical workers interested in this plant and also something regarding the results of economic significance that have been attained. The general methods of inbreeding corn are already

familiar, but for the sake of completeness it seems desirable to review them briefly.

ESTABLISHING SELFED LINES

Maize is admirably adapted for inbreeding studies. It is a naturally cross-fertilized crop that may easily be self fertilized. A single plant may produce 1,000 seeds. An addition to these characteristics, which make it attractive genetic material, is its great economic value.

Self pollination in maize may be accomplished by the simple expedient of placing suitable bags on the tassel and ear shoot, respectively, and at the proper time transferring the pollen to the silk. It is generally believed among corn geneticists that the inbred strains are quite homozygous after six or seven generations of self-fertilizations. Jones (4)[3] tested for homozygosity some lines of corn that had been selfed for 7 and 14 years. Those that had been selfed for the shorter period still showed appreciable heterozygosity with respect to height, number of nodes, length of ear, and yield, whereas those lines which had been selfed for the longer period did not give any evidence of heterozygosity with respect to height of plant and yield. For practical purposes, however, inbred lines of corn are usually sufficiently homozygous after 7 or 8 years of self-pollination.

LOSS OF VIGOR

Inbreeding experiments have given a real insight into the cosmopolitan nature of the corn plant. From any variety one may isolate almost any kind of corn, and some things that bear only a faint resemblance to corn, by simply practicing continued self pollination. Perhaps the most universal result of self pollination is the loss of vigor in the progeny. American plant breeders have isolated and studied several thousand inbred strains of corn, but to the writer's knowledge no one has succeeded in isolating a relatively homozygous line that is as vigorous as commercial corn. This is perhaps not surprising in view of the fact that maize carries 10 pairs of chromosomes and in them undoubtedly is contained a great number of genes concerned with the expression of vigor.

With the progress of genetic investigations it has become more and more evident that the manifestation of a character, even though simply inherited, is dependent on the interaction of many genes. Normal chlorophyll in maize is dependent for its expression on a considerable number of genes as has been shown by several workers. Mangelsdorf (9) has recently published evidence that dormancy of

[3]Reference by number is to "Literature Cited," p. 548.

seed in this plant is dependent upon at least 15 genetic factors. If the expression of a simple character such as this is dependent on a number of factors, it seems highly probable that the expression of vigor which may be manifest in many different characters is dependent on many more factors.

The number of different biotypes in maize that have been isolated is likely very small indeed compared with the number it is possible to isolate. The great number of genes involved in the expression of vigor, together with linkage, make the task of isolating a homozygous inbred strain as vigorous as, or more vigorous than, a commercial variety, seem remote, and yet the task is not necessarily a hopeless one. The number of artificially produced biotypes that have been studied in corn is not nearly as great as the number of pure lines that have been studied in wheat, which is naturally self pollinated. If corn could be artificially self pollinated as generally as wheat is naturally, vigorous strains which are homozygous would probably be isolated.

REACTION OF SELFED LINES TO SMUT

During the past 10 years at the West Virginia Agricultural Experiment Station an inbreeding experiment has been carried on which has for its object the isolation of relatively homozygous lines of maize resistant to smut. The smut epidemic is induced by scattering horse manure which, four or five days previously, has been treated with smut. The first application of the treated manure is made when the corn is about a foot high and two later applications are made at intervals of about 10 days. At each application the treated manure is scattered along the side of every third corn row. When the last application has been made, manure treated with smut has been placed between every two corn rows.

The data in Table 1 show the reaction to smut of some of the lines of maize which have been isolated by self pollination. The inbred strains not only show considerable difference in degree of susceptibility to smut, but some of them show consistent differences with respect to place of infection. Strains 5-2-2, etc., and 4-17-4, etc., have shown high resistance to smut during each of the 9 years the experiment has been carried on. Strain 6-10-1, etc., isolated from the Leaming variety, on the other hand, shows relatively high susceptibility. This strain, together with some of its sibs, was used as a check which was placed at intervals of about 10 rows in the nursery.

Of more interest perhaps than the difference between the resistant and susceptible strains is the apparent localization of in-

TABLE 1.—*The reaction of selfed strains of maize to smut.*

Strain No.	Year and number of plants grown, together with percentage and place of smut infection*									
	1922	1923	1924	1925	1926	1927	1928	1929	1930	Average
5-2-2-1-1, etc., Reid's Yellow Dent	52 0%	23 4.3%	24 0%	91 0%	94 1.1% 1L	96 1.0% 1b	94 2.1% 1e, 1b	95 1.1% 1e, 1b	90 2.2% 2 be	1.3%
4-17-4-1-1, etc., Boone County White	46 2.2%	22 0%	24 0%	65 3.1% 2 be	84 0%	9 0%	80 2.5% 2e	59 1.7% 1e	81 2.5% 1b, 1be	1.3%
8-15-1-1-2, etc., Cocke's Prolific	52 1.9%	24 25.0%	26 23.1%	93 24.7% 22t 1b	89 30.3% 25t 1e, 1Ls	87 14.9% 10t 3be, 1b 1Mul	83 66.3% 44t, 9 be, 6 b 4L 8Mul	99 56.6% 50t, 12be, 1e 7 Mul	96 18.7% 10be, 6b, 2t, 1e, 1Mul	29.1%
5-1-1-1-1, etc., Reid's Yellow Dent	47 2.1%	20 10%	19 5.3%	62 11.3% 4n, 2L 1 be	94 2.1% 2b	78 19.2% 14n, 1e	61 26.2% 13n, 2e 1b, 1be, 1ae, 1Ls 3Mul	100 17% 12n, 2 be, 1e 1L, 1t	98 5.1% 2n, 1be 1ae, 1Ls	10.9%
1-6-1-1-1, etc., Picken's White	50 2.8%	27 11.1%	26 19.2%	89 4.5% 3b, 1t	75 8.0% 2be, 2t, 1b 1e	54 7.4% 2b, 2n 1be 1Mul	68 10.3% 5be 1t, 1n	97 27.8% 17be, 5n, 3e 2ae, 1b 1Ls 2Mul	77 48.1% 30be, 7b, 2n 1e, 1Ls 4Mul	18.3%

3 – 10 – 2 – 2 – 1, etc., Eldridge	49 10.2%	19 0%	10 0%	84 15.5% 6e, 2be 2L, 2n 1b, 1t 1Mul	73 21.9% 14e 2t	94 20.2% 13n, 2e 2t, 1be 1ae	97 10.3% 5n, 3e 2t, 1ae 1Ls 2Mul	96 49.0% 41e, 4n 3ae, 1b 1t 3Mul	96 21.9% 13e, 3be, 2L 1ae, 1n 1t	16.6%
6 – 10 – 1 – 1 – 1, etc., Leaming	43 46.5%	150 23.3%	96 77.1%	130 55.4% 54be, 11n, 8t, 6L, 5e, 1b, 1ae, 1Ls, 15Mul	144 61.1% 41be, 21n 18Ls, 17e 13t, 12ae 10L, 5b 49Mul	201 68.2% 84be, 50t 27n, 15e 10L, 6ae 3Ls, 1b 59Mul	217 68.7% 73be, 52n 35t, 26e 15ae, 12Ls, 5L, 69Mul	168 81.0% 86be, 46n 36t, 34ae 25e, 11L 2Ls, 1b 104Mul	203 72.9% 122be, 37ae, 24n 20e, 5L, 3b, 2t, 5Ls, 70 Mul	61.6%

*The place of (not the appearance of) smut boils is indicated by the following letters: t = tassel; ae = above ear; e = ear; be = below ear; b = base; L = leaf; ls = leaf sheath; n = neck (just below tassel); Mul = number of plants which developed smut boils in more than one part of the plant.

fection in certain susceptible strains. Strain 8–15–1, etc., was predominantly infected in the tassel each year of the experiment except in 1930, which was an abnormally dry year. In fact so little rain fell during that growing season that many of the tassels dried prematurely, a fact which may account for their escaping smut infection. Strain 6–10–1, etc., also showed a low smut infection in the tassel in 1930, although during previous years it had shown considerable infection in this part of the plant. Strain 1–6–1, etc., isolated from Pickens White, showed considerable infection at the region of the plant noted as "below ear;" this being particularly true in 1929 and 1930. Smut boils developed in greater numbers on the region immediately below the tassel in plants of strain 5–1–1, etc., and on the ear in plants of strain 3–10–2, etc. It is interesting to speculate as to the cause of this difference in the reaction of the host to the fungus among the selfed lines of maize.

The difference cannot be explained adequately on the basis of different biologic forms of smut. It has been shown by Stakman and Christensen (12) that strikingly different biologic forms of smut do occur. It is quite unlikely, however, that one biologic form of smut would be confined to one row of selfed maize in this experiment because the different selfed lines were planted in adjacent rows. It seems more probable that the genetic differences are in the host plants. Perhaps we are dealing with two kinds of genetic factors, one kind concerned with the physiology of resistance and the other with the morphology of the corn plant. Since smut in maize is a matter of local infection, it is probable that the continued inbreeding has isolated lines that, because of certain morphological characters, are particularly accessible to the smut spores in certain regions of the plants. No matter what may be the true explanation, it is perfectly obvious that inbreeding has served to isolate relatively homozygous lines of maize which react very differently toward smut

What has been said concerning the variation among selfed lines with regard to resistance to a certain disease is equally true for a character like yield of grain. Selfed lines of maize differ strikingly with regard to yield of grain. Their ability in this regard varies all the way from complete sterility to a fair yield of grain, but in no case has the yield of a selfed line equalled that of the better commercial varieties.

UTILIZATION OF SELFED LINES

FIRST GENERATION CROSSES

After selfed lines have been isolated by means of several generations of artificial pollination the question of how they may best be

utilized arises. It has been shown repeatedly that first generation crosses between selfed lines frequently yield significantly more than the open-pollinated variety or varieties from which they were isolated. The greatest handicap in the utilization of first generation crosses for increased yields is the relative unproductiveness of the selfed lines. Jenkins (3) and others have shown that high-yielding first generation crosses are not wholly the result of chance combinations but occur very definitely among the crosses involving certain outstanding parent lines. Some correlation was obtained between the yield of F_1 crosses and that of the parent lines.

Another objection to using selfed lines directly in the production of first generation progeny is that the crossed seed is usually small and irregular. In a particularly unfavorable season this may be a considerable handicap. Even though a first generation plant, once it is established, may grow very rapidly and vigorously, its early growth may have been very much retarded, owing, presumably, to the small, inferior endosperm. Irregularity of seed shape makes it extremely difficult to obtain a "uniform drop" with a planter. To overcome the handicap of small, irregular crossed seed and of unproductiveness of the selfed lines, Jones at the Connecticut Experiment Station first proposed double crosses.

DOUBLE CROSSES

The method of double crosses may best be described by an illustration. Suppose that four selfed lines, A, B, C, and D, have been isolated and that first generation crosses between any two of them are highly satisfactory from the standpoint of productiveness. With this material at hand the next step is to produce a first generation cross between A and B and one between C and D. The seed which is then used for commercial planting is produced by crossing the two kinds of first generation hybrids. This may easily be done by interplanting F_1 (A x B) with F_1 (C x D) and detasseling one of them. As will be shown later, double crosses have outyielded ordinary commercial varieties in numerous trials. The main objection to this method of corn breeding is that it is somewhat involved and rather expensive for the corn grower.

A simplification of the method was first suggested by Jones and Mangelsdorf (5) and later by Kiesselbach (7) who supplied experimental evidence and additional details. Essentially, the simplification consists of maintaining each of the two single crosses that enter into a double cross as isolated, open-pollinated varieties. Kiesselbach did not obtain a significant difference among the average

yields of several double cross combinations between the F_1, F_2, and F_3 single crosses, respectively.

SYNTHETIC CROSSES

Another method of utilizing selfed lines of maize to increase production has been called synthetic crosses. In this method any number of selfed lines may be brought together by hybridization. Two general plans have been followed. In one plan only those lines which "nick well" or, stated another way, only those lines which give satisfactory single crosses are brought together, whereas in the other and less desirable plan no systematic effort is made to determine the desirability of first generation crosses between all pairs of the selfed lines it is proposed to synthesize. In both methods the synthesized variety, after the selfed lines are brought together by hybridization, is established and maintained by mass selection as is any commercial variety of maize. This is a distinct advantage from the standpoint of the corn grower.

Resynthesized varieties have been used successfully in the production of first generation crosses. Canada-Leaming, developed by the Connecticut Experiment Station, is a first generation cross between a combination of the better selfed strains isolated from Canada Yellow flint and a combination of the better selfed strains isolated from Leaming.

BACK CROSSES

Several years ago Harlan and Pope (1) suggested that back crosses might be used more extensively in the breeding of small grains. More recently, Richey (10) has suggested a method of corn breeding which involves crossing, back pollinating, and selfing, all accompanied by selection.

The variety of corn, Woodburn White Dent, grown at the Lakin Experiment Farm located in Mason County, West Virginia, produced as an average 10 bushels per acre more grain than the next highest yielding variety during a period of 4 years. Woodburn White Dent is now being grown by some of the farmers in the neighborhood of the experiment farm, but it is disliked by some because it has white seed.

An experiment has been begun which has for its object the synthesis of a new variety which will combine the high-yielding ability of Woodburn White Dent with yellow color of seed and perhaps resistance to smut. A cross was made between a relatively smut-resistant, selfed line, isolated from the variety Reid's Yellow Dent,

and Woodburn White Dent. The cross was made by collecting a composite sample of pollen from approximately 25 Woodburn White Dent plants and, after mixing the pollen, applying it to several plants of the yellow selfed strain. It is planned to plant this crossed seed and pollinate a considerable number of the resulting plants with a composite of Woodburn White Dent pollen. The aim is to continue this process for 7 or 8 years, each year planting only the yellow crossed seed and back-crossing to the Woodburn White Dent.

It is also planned to grow each year under smut epidemic conditions the plants to be used as the maternal parents. In selecting crossed seed for establishing the next generation those plants which show evidence of smut infection will be avoided. After backcrossing has been completed, it is planned to self several hundred plants for not more than two generations and, on the basis of the progeny test, determine what material, particularly from the standpoint of color of grain and resistance to smut, is to constitute the new variety.

RESULTS OF ECONOMIC SIGNIFICANCE

CONNECTICUT

In a recent letter Dr. D. F. Jones states, "Burr-Leaming (a double cross) corn was first grown for commercial seed production in 1921. Seed is now being produced by four different seed growers. The actual amount grown by the farmers last year was something around 500 acres. This corn has a limited area of adaptation in which it seems to do exceptionally well, standing erect when other varieties of corn are blown down, and in tests covering seven years' trials has produced 17 % more grain than the next highest yielding variety. Canada-Leaming has only been produced commercially two years and is still somewhat in the experimental stage. A large number of trials indicate outstanding value for many sections of New York and New England. Seed is being produced by four different growers this year. Both of these types are multiple crosses, being first generation hybrids of synthetic varieties.

"The most extensive use is being made of two of our single crosses of canning sweet corn. These are the Crosgreen and Redgreen combination of white sweet corn. This year the Associated Seed Growers have 50 acres in seed crossing fields for the production of this seed from inbred strains. This corn is used by the canners in Maryland and New York.

"We now have several promising hybrids of early yellow sweet corn especially developed for market gardeners, and the Associated Seed Growers are developing a number of very promising hybrids for use by canners."

In view of these facts it is obvious that the corn-breeding program in Connecticut has found fruition in increased yields. If these improved strains now available were generally distributed in the areas

to which they are adapted there undoubtedly would result a higher average yield per acre.

IOWA

The Iowa Experiment Station in cooperation with the United States Department of Agriculture has extensive corn-breeding projects under way. Beginning with 1926, tests (11) have been conducted in 12 districts of Iowa to compare the yielding ability of open-pollinated strains of corn produced without inbreeding and hybrid strains involving one or more inbred lines in their creation. During the period of the tests several hundred of both open-pollinated and hybrid strains have been grown in replicated plats located in the 12 districts into which the state was divided. Average yields of the hybrid strains expressed as percentage of average yields of the open-pollinated strains are as follows: 1926, 107.0%; 1927, 106.8%; 1928, 110.5%; 1929, 110.6%; average for the four years, 108.7%.

Professor Hughes of the Iowa station estimates that there was approximately 4,500 acres of hybrid corn grown by Iowa farmers during 1930 and that there will be a marked increase in this acreage in 1931. Approximately 10 million acres of corn with an average yield of about 40 bushels per acre are grown in Iowa each year. In view is of the data obtained in the corn yield tests mentioned above, it perhaps ultra-conservative to estimate that the average yield per acre of corn in the state could be increased 5% by the use of hybrid strains. This would mean an increased annual production of about 20 million bushels. The gross value of the increased yield for a single year would be over 10 million dollars. However, net value is the thing of interest to the farmer and in arriving at this, one must take into account the increased cost of producing hybrid seed.

H. A. Wallace, a prominent corn breeder of Iowa, has obtained actual cost records on the production of hybrid seed corn per bushel sold. The computations were based on a 3-year average and a 1,500-bushel unit. The total cost per bushel, including commissions on sales, was found to be $9.00. If it is assumed that the difference in the cost of hybrid seed and open-pollinated seed is $6.00 and that 1 bushel of seed will plant 6 acres, it is apparent that the increased cost of the hybrid seed is almost equal to the value of a 5% increase in average yield. These figures are mentioned not to belittle the economic importance of corn breeding work, but rather to stress the point that in order that hybrid seed may be a sound investment for the farmer it must possess a yielding ability that is markedly superior to open-pollinated seed. As a matter of fact, the above de-

ductions are based on an assumed increased yield from the use of hybrid seed that probably is too low. The use of the better hybrid strains would likely give an increase in yield of at least 10%. Then, too, the cost of producing the hybrid seed as given by Mr. Wallace may be reduced somewhat.

NEBRASKA

A few years ago Kiesselbach (6) showed that single crosses and double crosses of selfed lines required much less water per unit of dry matter elaborated by the plants than did the selfed lines and considerable less than did the F_2 generation descendants from the selfed lines. In other words, there seemed to be a relationship between heterozygosity and water requirement per unit of dry matter—a relationship which may be of considerable economic significance in areas of limited rainfall.

The yield records of from 20 to 30 hybrid strains compared with commercial varieties for a period of 3 years have been published (8). During 2 years tests were conducted at three places and during 1 year at four places in Nebraska. The average yields of the better hybrids expressed as percentages of average yields of the better varieties are as follows: In 1927, 110.3%; in 1928, 141.3%; and in 1929, 116.5%. Kiesselbach estimated the acreage of hybrid corn grown in Nebraska during 1930 to be about 3,000 acres.

MINNESOTA

The Minnesota Station has for some time made a systematic and rather extensive search for selfed lines which would give superior yields in double cross combinations. Hayes (2) presented data a year ago which showed that there had been obtained definite increases in yield with certain double crosses of field corn and rather striking increases in yields with some single crosses between selfed lines of Golden Bantam sweet corn. The yielding ability of the double crosses was tested in comparison with that of two commercial varieties for a period of 4 years and at five different places in Minnesota. The average yields during the period of the test for the double crosses expressed as percentage of the average yield of Rustler, the higher yielding commercial variety, were 109.0%, 109.7%, and 112.1%, respectively. In 1929, the five first generation crosses between lines of Golden Bantam sweet corn selfed for 6 to 7 years yielded from 22% to 69% more corn than did the open-pollinated Golden Bantam variety.

During the past year the Minnesota Station has carried on in 44 counties yield trials in which comparisons were made between open-

pollinated varieties and three different double crosses. The 44 counties were grouped into six districts representing six areas in the state. The results of these comparative trials, which were kindly supplied by Dr. H. K. Hayes, are shown in Table 2. Each yield determination was based on 50 hills.

The double crosses are adapted particularly to districts I to V. District VI, which represents the southern section of Minnesota, will mature varieties that require a considerably longer growing season than that required by the double crosses. Even in this district the double crosses outyielded the open-pollinated varieties in 59 of the 95 trials, although the average increase in yield was small. In districts I to V, inclusive, double crosses gave the greater average yields in 166 of the 203 tests. The average yield of the crosses in these districts was 112.4% of the average yield of the open-pollinated varieties.

TABLE 2.—*Relative yields of three double crosses of corn compared with open-pollinated varieties on farms in Minnesota during 1930.*

District	Crosses	No. of trials	No. of trials in which cross excelled	Yield of cross in percent of open-pollinated corn
I	E x I	11	11	126.2
	E x L	9	8	124.6
II	E x I	17	14	112.6
	E x L	9	7	123.3
III	E x I	56	45	106.7
	E x K	3	3	121.5
	E x L	6	5	107.5
	E x I	30	25	113.5
IV	E x K	3	3	110.5
	E x L	3	2	111.1
V	E x I	49	39	112.3
	E x K	7	4	102.4
VI	E x I	87	53	103.5
	E x K	8	6	103.8
Total I to V, inc.	Three crosses	203	166	112.4

Dr. Hayes states that the total amount of seed of these three double crosses in the hands of farmers and available for planting in 1931 is as follows: E x I, 202 bushels; E x K, 967 bushels; and E x L, 60 bushels. It is expected that several hundred acres will be used for seed production in 1931.

OTHER STATES

The results which have been reported above are typical of those which have been attained elsewhere. The Ohio Experiment Station, in cooperation with the United States Department of Agriculture, found considerable difference in the relative response of selfed lines to different levels of soil productivity. Some of the selfed lines yielded relatively better on a "poor" soil, others on a "rich" soil.

The estimates[4] of the amount of hybrid corn grown by farmers in 1930, in states other than those which have been mentioned, are as follows: Illinois, 12,000 acres; Indiana, 6,000 acres; Kansas, 4,000 acres; Missouri, 2,500 acres; and Ohio, 1,000 acres.

In addition to the work being carried on by state and federal agencies, a number of commercial seedsmen have adopted the practice of inbreeding maize with the express purpose of producing superior yielding strains in hybrid combinations.

In a recent letter, Dr. E. G. Sieveking, of the Funk Brothers Seed Company, informed the writer that enough hybrid seed corn to plant 10,000 acres was distributed by that company in each of the 2 years, 1929 and 1930. Comparative yield data collected in 1930 in eight different places in one instance and seven in the other showed that both Funk's Hybrid 517 and Funk's Hybrid 365 yielded, on the average, considerably more than the respective open-pollinated varieties with which they were compared.

CONCLUSIONS

As a result of the intensive and extensive genic analyses of maize that have been carried on, the genetics of this plant is perhaps more thoroughly understood than that of any other one. Most of the characters that have been studied are not of direct agronomic importance. However, the determination of the manner of inheritance of these characters, the studies of hybrid vigor, and the earlier attempts to increase yield by breeding, all have helped to formulate the methods that are being used at present by technical breeders who are seeking to produce superior yields. The methods which have been most successful to date seem to possess one feature in common, namely, the utilization of a first generation cross as the superior yielding form. The problem then is to create strains of maize which are at least fairly productive, which produce seeds of sufficient size and uniformity to be dropped by a planter satisfactorily, and which

[4]In most cases the estimates were made by agronomists interested in corn improvement.

give in first generation crosses yields that are distinctly greater than those of the better open-pollinated varieties.

The corn breeding program has been carried forward to the point where results of economic importance are beginning to be realized. There was in the neighborhood of 30,000 acres of hybrid corn grown in the United States last year. Relative yield data indicate that a 10% increase in the yields of hybrid strains over the ordinary commercial varieties may reasonably be expected. If it is assumed that one-half this increase is profit, the potential annual value of the inbreeding experiments with maize in the United States is the equivalent of about 130 million bushels of corn, or about 5% of the present annual crop.

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BROWN MIDRIB IN MAIZE AND ITS LINKAGE RELATIONS[1]

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As the name implies, the plants possessing this brown midrib character show a browning of the midrib of the leaves. The pigment usually appears when the plant has four or five leaves but has been observed to appear as early as the three-leaf stage and as late as the six-leaf stage.

The major part of the material was turned over to the writer by the Division of Agronomy and Plant Genetics in 1926, after many of the crosses had been made. The study reported here consists of a description of the character; its location in the plant; physiologic, morphologic, and biochemical studies of the character; and a study of the mode of inheritance and linkage relations.

DESCRIPTION OF THE CHARACTER

The brown midrib character reported here appeared in Culture No. 113 from Ear No. 90-4 in a one-year self-pollinated line of Northwestern Dent corn at University Farm, St. Paul, Minnesota, in 1924. The pigmentation to which this character is due has been found in the stem, the root, the leaves, the tassel, and the cob of the plant. It could not be detected in the pollen grains or in the kernels. It is present only in the lignified tissue. In the green tissues, it is masked by the chlorophyll, but it shows up in the midrib because of the meager supply of chlorophyll there. The chlorophyll can be removed by using alcohol, acetone, or acetic acid, and the brown pigment remains as it is more insoluble than the chlorophyll.

The pigmentation takes place during the growth of the cell when the cell organization is complete. It is preceded by lignin formation. The cell contents, as they appear under an oil immersion lens, contain no colored products. The pigment appears in the

[1]A thesis presented to the faculty of the graduate school of the University of Minnesota in partial fulfillment of the requirements for the degree of doctor of philosophy. The major part of the material and facilities for conducting most of the inheritance studies were furnished by the Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minn. Paper No. 1000 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication January 26, 1931.

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leaves and the roots at about the same time. The lignified tissue first forms within the fibro-vascular bundles of the plant, and here the brown pigment also first forms. The pigment is present in the cell walls of the tracheae but not in those of the tracheids. When commencing to form, it is a light yellowish color. This later turns to a dark orange brown.

An effort was made to determine whether the pigment could develop in the dark. Five pots of soil containing six seeds each were placed in a dark room and a similar number of pots as checks were placed outside the dark room at the same temperature. All of the plants in the dark room grew to the three- and four-leaf stage, but under those conditions no brown pigment formed. The plants outside the dark room grew more vigorously; and at the same stage of growth 12 of the plants in the four-leaf stage showed the brown midrib character.

THE CHEMISTRY AND PHYSIOLOGY OF THE CHARACTER

Samples of corn differing chiefly in the presence and absence of the brown color were grown in pots of soil in the greenhouse and their H-ion concentration, osmotic pressure in atmospheres, and electrical conductivity determined at the 4- to 6- and 10- to 12-leaf stages. The freezing point readings, from which the osmotic pressures were determined, were corrected by the formula of Harris and Gortner (16).[3] The data are contained in Table 1.

TABLE 1.—*Hydrogen-ion concentration, osmotic pressure, and electrical conductivity of brown midrib and normal plants.*

	Brown midrib plants		Normal plants	
	4 to 6-leaf stage	10 to 12-leaf stage	4 to 6-leaf stage	10 to 12-leaf stage
Cc juice pressed out per 100 grams of green plants....	58.9	55.2	64.4	63.2
pH....................	5.45	5.75	5.30	5.60
Osmotic pressure, atmospheres..................	7.529	9.983	7.443	10.482
Electrical conductivity, ohms..................	0.0127	0.0123	0.0150	0.0136

Pigmented material was collected from the plants during the late summer and fall and the usual chemical tests (24, 25) showed that the pigment was not carotin, xanthophyll, tannin, anthocyanin, or a

[3]Reference by number is to "Literature Cited," p. 556.

flavone or flavonal pigment. These macrochemical tests were substantiated by microchemical tests (8). These tests also indicated that the brown pigment was not a pectic compound. It was either a compound of the lignified tissue or was deposited in the interstices of it and could not be separated from it by the solvents used.

CROSSES WITH OTHER BROWN MIDRIB CHARACTERS

Plants with this brown midrib character have been crossed with brown midrib plants used by Kiesselbach (21) and by Eyster (14) and with a brown midrib found in Del Maiz sweet corn at Minnesota and two sweet corn cultures having the character at Ohio State University. They were found to be due to identical factors. This character was found to be due to a different factor than that of one culture furnished by C. R. Burnham of Wisconsin. Other crosses have been made, but the progeny have not yet been tested.

INHERITANCE OF THE BROWN MIDRIB CHARACTER

Pollen mother cells of brown midrib plants were treated with Belling's solution and examined under the microscope. Four counts of 10 pairs of chromosomes each were made. No deviations from the normal number or type were observed.

The brown midrib character is a simple Mendelian recessive and relatively easy to study. It is a mature plant character appearing in the early stages of plant growth, and does not seem to affect the vigor of the plant. From various crosses of normal and brown midrib plants there were obtained, in the F_2 generation, 35,420 normal plants and 11,237 brown midrib plants. The deviation in numbers from a 3:1 ratio was 427 with a probable error in numbers of 630.

METHODS USED IN STUDYING THE LINKAGE RELATION OF THE BROWN MIDRIB FACTOR PAIR

Studies of the linkage relations of this brown midrib factor pair with widely separated genetic factor pairs in each of the published linkage groups have been made. A list of the factors used in this study and a description of the character is given below. The factors for dominant characters are capitalized.

A Anthocyanin color for pigmentation of aleurone with *C* and *R* and for plant color. (Emerson 1918, 1921) (11, 13)

bm Brown midrib for pigmentation of the lignified tissue throughout the plant. It shows up as a browning of the midrib of the leaves in green plants. (Kiesselbach, 1922; Eyster, 1926; described here) (14, 21)

Bn Brown aleurone for brown pigment, strictly limited to the aleurone grains. (Kvakan, 1924) (22)

br	Brachytic culms. A shortening of the internodes on the main culm and lateral branches without a reduction in the number or in the number and size of other organs. (Kempton, 1920) (20)
C	Aleurone color with *A* and *R*. (East and Hayes, 1911; Emerson, 1918) (7, 11)
fl	Floury endosperm. (Hayes and East, 1915) (19)
g	Golden plant color. (Lindstrom, 1918) (23)
gl	Glossy seedlings. (Kvakan lists as unpublished data in 1924) (22)
j	Japonica white striped leaves. (Lindstrom, 1918) (23)
lg	Ligule-less leaves. (Emerson, 1912) (10)
P	Pericarp color. (Emerson, 1911) (9)
pg	Pale green seedlings. (Brunson, 1924) (2)
pg_2	Pale green seedlings (Demerec 1924) (6)
Pl	Purple plant color. (Emerson, 1921) (13)
Pr	Purple aleurone in connection with the other aleurone color factors. (East and Hayes, 1911; Emerson, 1918) (7, 11)
R	Aleurone color in combination with *A* and *C*. (East and Hayes, 1911; Emerson, 1918 and 1921) (7, 11, 13)
ra	Ramosa ear. External appearance of being composed of a mass of kernels borne on numerous irregular branches. Tassels much branched and cone shaped. (Gernert, 1912) (15)
sh	Shrunken endosperm. (Hutchinson, 1921) (18)
sm	Salmon colored silk. (Anderson, 1921) (1)
su	Sugary endosperm (East and Hayes, 1911) (7)
ts_1	Tassel seed. A pistillate plant. (Emerson, 1920) (12)
ts_2	Tassel seed. A pistillate plant. (Emerson, 1920) (12)
ts_4	Tassel seed. A pistillate plant. (Phipps 1928) (28)
Tu	Tunicate ear or podded corn. (East and Hayes, 1911; Collins, 1917) (7, 4)
w_1	White seedling. (Lindstrom, 1918) (23)
w	White seedling. Relation to known *w* factors undetermined.
wx	Waxy endosperm. (Collins, 1909) (3)
Y	Yellow colored endosperm (East and Hayes, 1911) (7)

These studies of linkage relations were made in all cases by the use of the F_2 generation for the characters concerned. The values for p were calculated by the product method, when the four observed F_2 classes of zygotes were represented by $\frac{AB}{(a)}\frac{Ab}{(b)}\frac{aB}{(c)}\frac{ab}{(d)}$ and $\frac{Total}{N}$. For the repulsion phase, $\frac{ad}{bc}$ was calculated; and for the coupling phase, $\frac{bc}{ad}$, and the recombination value determined from tables prepared by Immer (19). The probable errors, expressed as decimal fractions, were obtained from the same tables by dividing the appropriate factor by $\sqrt{N}$.

For the 1:1 and 3:1 ratios, in the repulsion phase, the formula (5, 26) $p = \frac{2(AB—ab)}{N} — .5$ was used where AB and ab contain the new

combination of characters. At present no probable error has been developed for this.

TABLE 2.—*Recombinations of the Bmbm factor pair with various other genetic factor pairs*

Linkage group	Linkage phase	*bm* with	XY	Xy	xY	xy	Total	Recombination value
C–Wx	Repulsion	*sh*	1,426	388	467	180	2,461	54.9±1.0
	Repulsion	*wx*	1,462	423	462	159	2,502	52.5±1.0
	Coupling	C	690	225	211	81	1,207	47.7±1.4
R–G₁	Repulsion	Pg_1*	832	267	341	died	1,440	——
	Repulsion	*g*	2,239	729	524	212	3,704	53.1±0.8
	Coupling	*CR*	1,829	563	1,624	526	4,542	49.0±1.1
Su–Tu	Repulsion	*su*	3,251	1,070	733	285	5,339	52.3±0.7
	Coupling	*Tu*	390	128	164	43	725	53.2±1.9
B–Lg	Repulsion	*lg*	843	272	284	83	1,482	48.6±1.3
	Repulsion	ts_1	632	212	202	69	1,115	50.3±1.5
	Repulsion	*fl*	726	244	630	197	1,797	52.7
Y–Pl	Coupling	*Y*	2,710	762	1,122	317	4,911	50.0±0.7
	Coupling	*Pl*	1,123	232	369	139	1,863	41.7±1.1
	Repulsion	*sm*	1,211	438	370	123	2,142	48.9±1.1
	Repulsion	w_1†	1,178	373	575	died	2,126	——
P–Br	Repulsion	*br*	693	204	219	78	1,194	52.7±1.4
	Repulsion	*P*	402	130	142	41	715	48.4±1.9
	Repulsion	ts_2	624	211	201	68	1,104	50.0±1.5
Ra–Gl₁	Repulsion	gl_1	1,410	368	334	114	2,226	53.8±1.0
	Repulsion	*bv*	667	197	220	69	1,153	50.8±1.5
	Repulsion	*ra*	746	273	195	110	1,324	56.0±1.3
D_1–Pg_2	Repulsion	pg_2	657	198	223	72	1,150	51.0±1.5
Pr–V	Repulsion	*Pr*	673	269	274	18	1,234	26.3±1.8
	Repulsion	*Pr*	259	145	122	14	540	28.8±2.6
	Repulsion	*Pr*	1,336	552	543	45	2,496	28.3±1.2
A–Ts₄	Repulsion	ts_4	1,265	423	431	142	2,261	49.8±1.1
	Coupling	*A*	806	264	256	86	1,412	49.8±1.3
Not yet placed in linkage	Repulsion	*j*	1,244	381	348	107	2,080	50.0±1.1
	Repulsion	*w*‡	1,719	542	728	died	2,989	——

*In the studies with Pg_1 there was a good fit to a 3:1 ratio of normal to brown midrib plants in the Pg_1 group.

†There was also a good fit to a 3:1 ratio of *Bm* to *bm* plants in the plants which carried the W_1 factor.

‡This was likewise true in the recombinations obtained with this factor pair.

In some populations, the observed data were compared with theoretical values (5, 26) in which the observed ratios were maintained for each pair of characters and the theoretical values were calculated on the basis that the two character pairs segregated independently

and the probability determined that the observed values may or may not be explained on the basis of independent segregation. The values of P for X^2 where n′ = 2 were obtained from tables (27).

The relation of a few factor pairs was studied in which the plants in the homozygous condition for those factors died in the seedling stage. The segregation for the *Bmbm* factor pair could be detected only in the plants normal for the other factor pairs concerned. The deviation from a 3:1 ratio of the normal and brown midrib plants in these populations was calculated and the odds obtained against the occurrence of as great or greater a deviation due to the errors of random sampling.

The recombination values of the brown midrib factor pair, which has been designated *Bmbm*, with the factor pairs in other linkage groups are given in Table 2.

Only those crosses are discussed in which the recombination values obtained deviate from the expected for independent inheritance by more than 3 times the probable error.

The value for *P* obtained from the recombinations with the *Sh sh* factor pair deviates from the expected for independent inheritance by nearly 5 times the probable error. The odds against the occurrence of as great or greater a deviation due to the errors of random sampling are 1,350:1. The X^2 value for goodness of fit for independent inheritance is 11.11 with a *P* value of .0009. As great or greater a deviation might be expected on the basis of the errors of random sampling 9 times in 10,000 trials. The evidence indicates the possibility of a slight linkage with more than 50% of recombinations between the *Bmbm* and *Shsh* factor pairs. Studies with *Cc* and *Wxwx* factor pairs, together with the known map positions of *C*, *sh*, and *wx*, lead to the conclusion that *bm* is independent in inheritance of the factors in the *C-Wx* linkage group.

In the *R–G*$_1$ linkage group the recombination value with g_1 is 53.1 + 0.8. Odds that as great or greater a deviation is not due to the errors of random sampling are 95:1. Here the value of X^2 for independent inheritance is 5.60 with a value for P of .0187. As great or greater a deviation might be expected on the basis of the errors of random sampling about 2 times in 100 trials. Studies with other factor pairs in this linkage group indicate independent inheritance.

In the *Su–Tu* linkage group there is an indication of a slight linkage with Susu with more than 50% of recombinations of characters. Data from two cultures in this population indicated independent inheritance and two indicated a slight linkage. In the two cultures showing linkage there were too few sugary seeds and the odds were

high that this was not due to chance. Considering the data with *Tu tu* and the known map positions of these factor pairs, the results seem best explained by the hypothesis of independent inheritance.

In the *Y–Pl* linkage group the value for *P* obtained with the *Plpl* factor pair is .417 ± .011 which is a deviation from the expected for independent inheritance of 7.8 times the probable error. This can be accounted for by the difficulty in classifying the *bm* plants in the *Pl* group when the purple color was too well developed. With *Yy* and *Smsm* the results indicate independent inheritance.

In the Ra–Gl_1 linkage group, recombinations of *ra* and *bm* gave a *p* value of 56.0 ± 1.3. Odds that this deviation is not due to chance are 656:1. The value of X^2 for independent inheritance is 9.82 with a value for *P* of .0018. On the basis of random sampling as great or greater a deviation might be expected 177 times in 100,000 trials. There were too few *rabm* plants. No explanation for this can be given.

With the Gl_1gl_1 factor pair a value for *p* of .538 ± .010 was obtained. Odds that this deviation is not due to chance are 78:1. Using X^2 for independent inheritance as great or greater a deviation might be expected 3 times in 100 trials.

There is an indication of a slight linkage with the *Rara* and Gl_1gl_1 factor pairs and independent inheritance with the *Bnbn* factor pair. Considering the linkage relations of the factor pairs of this linkage group and the crossover percentages obtained with the *Bmbm* factor pair, the results appear to be explained most satisfactorily on the basis of independent inheritance.

In the Pr–V_2 linkage group wide deviations from the expected for independent were obtained with the *Prpr* factor pair. In three crosses values for *p* of .263 ± .018, .282 ± .012, and .288 ± .026 were obtained.

The difference between the highest and lowest crossover percentages is but 2.5 ± 3.2. Eyster (14) reported a linkage between these two factor pairs with a crossover of 20%. No data were presented to confirm this statement.

CONCLUSION

A brown midrib character, due to a factor pair designated *Bmbm*, was inherited as a simple Mendelian recessive. This color was located in the lignified tissue of the entire plant. Its formation started after lignified tissue was formed, and while cell organization was complete. It was not contained in the cytoplasm of the cell and was either a compound of lignin or was laid down in the in-

terstices of the lignified tissue and could not be separated from it. It was not carotin, xanthophyll, tannin, anthocyanin, or a flavone or flavonol pigment. It was not produced in the dark. Juices extracted from brown midrib plants grown under greenhouse conditions were slightly less acid than comparable normal plants. The osmotic pressure of these juices was about one-half an atmosphere higher in the normal plants at the 10- to 12-leaf stage. The electrical conductivity was slightly higher in the juices from the normal plants.

This factor pair was inherited independently of the *C–Wx*, *R–G*$_1$, *Su–Tu*, *B–Lg*, *Y–Pl*, *P–Br*, *Ra–Gl*$_1$, and *A–Ts*$_4$ linkage groups. It was also inherited independently of the *Ji*, *Ww*, and *Pg*$_2$ *pg*$_2$ factor pairs. It was linked in inheritance with the *Prpr* factor pair of the *Pr–V*$_2$ linkage group. The crossover percentages obtained in three crosses were 26.3 ± 1.8, 28.3 ± 1.2, and 28.8 ± 2.6.

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A COMPARISON OF DOCKAGE ASSESSMENTS WITH TOTAL SCREENINGS[1]

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The correct estimation of the amount of foreign substances present in a carlot of wheat as it arrives at the terminal market for disposal to buyers presents a problem of considerable importance to the producer, the seller, and the buyer, who, in most cases, is the miller. The reports on dockage and foreign material other than dockage presented by the state grain inspection departments and licensed inspectors, in accordance with the directions of the Handbook of Official Grain Standards, represent careful endeavors toward the estimation from samples of the proportions of good sound wheat, straw, foreign grains, etc., present in the entire bulk sampled.

The economic importance of a correct estimation of dockage in wheat arriving at terminal markets in the United States becomes clear from the fact that an average error of only 0.5% less estimated dockage than might be actually found from cleaning all the wheat would result for the average post-war crop in a gain to the sellers and a loss to the buyers of approximately 4.2 million bushels of grain *per annum*. In accordance with official statements, material thus classed as dockage should correspond closely to the screenings derived from the bulk grain by the customary cleaning machinery used in commercial mills. The separators of this class in use at the Minnesota State Testing Mill have been described in Bulletin 23 of the Minnesota State Department of Agriculture, and represent standard cleaning machinery of modern milling practice. The screenings from the receiving and milling separators have been grouped as one unit in this study and will be referred to as total mill screenings.

SOURCE OF DATA

The data embodied in this discussion have been published in full in the annual reports of operation of the Minnesota State Testing Mill by Bailey (1, 2),[3] Bailey and Sherwood (3), and Sherwood (5, 6, 7), covering the crop seasons of 1921 to 1926, inclusive. Wheats of the hard red spring class plus a very few white wheats

[1]Joint contribution from the State Testing Mill, Minneapolis, Minn., and the Department of Botany, University of Minnesota, Minneapolis. Received for publication January 24, 1931.

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[3]Reference by number is to "Literature Cited," p. 571.

have been taken into consideration in the following calculations. Winter wheats have not been included in order to maintain a desirable uniformity of data. While a small number of the carlots of wheat were shipped from points in Montana and the Dakotas, the majority originated in Minnesota and represent a cross-section of the crops grown in that state.

All cars were assessed for dockage by the State Grain Inspection Department at Minneapolis, the wheat having been purchased in nearly all cases in the latter market. Perfect agreement between the amount of dockage estimated, and the amount of screenings that a commercial mill might secure from the entire carlots may never be expected, if for no other reason than because of the errors due to either random or systematic sampling.

The sampling error of the accepted inspection method has not been reported in the literature. Nor is it possible at present to determine, with the precision that is desirable, the magnitude of this error from any published data. It is important that such work should be carefully carried out and that reliable standards be established for the guidance of inspectors and parties engaging in wheat commerce, the more particularly to secure equitable judgments in cases of appeals based on slightly differing reports made by different or even the same workers. In the absence of standards of variability to be expected purely by chance, it remains important to consider the deviations which may be found to exist between dockage values determined from single composite samples of cars of wheat, and the screening loss determinations secured from the cleaning machinery of commercial mills. It is the purpose of this paper to present a comparison of the percentage dockage estimated by inspectors with the percentage of total screenings derived from the carlots of wheat as determined at the Minnesota State Testing Mill during the crop seasons of 1921 to 1926, inclusive.

Assessed dockage may be defined as the coarse foreign material in addition to the finer screenings obtained by hand sieving. These groups comprise, in general, straw, chaff, earthy materials, weed stems, grain other than wheat, weed seeds, and any other foreign material which can be removed readily from the wheat by the use of appropriate sieves or cleaning devices. In a few cases the dockage listed in the annual reports of the mill is the verdict of a reinspection by officers of the Federal Grain Supervision Department in Minneapolis; otherwise the figure given is that of the State Grain Inspection Department. In nearly all cases the analysis for percentage dockage was repeated at the State Testing Mill. The latter figures have not been published in the annual reports of the Mill, but an analysis of

them is introduced in the following discussion because of their pertinance to the problems under consideration. They will be referred to as "mill dockage" in contrast to the "official dockage" estimates of the state and federal department.

RESULTS

The average official and mill dockage and average total mill screenings for each crop season, together with the average test weight per bushel in each case, are presented as Table 1. The number of carlots of wheat upon which the constants for each season are based is given in column 2 of the table, the figures in parenthesis referring to the more limited data in the first three seasons for mill dockage and ($\bar{s}$-$\bar{d}$).

TABLE 1.—*Average yields of official dockage, mill dockage, and total mill screenings for each crop season.*

Crop season (1)	N (2)	Test weight per bushel (3)	Average			
			Official dockage ($\bar{D}$)	Mill dockage ($\bar{d}$)	Screenings ($\bar{s}$)	Difference ($\bar{s}$–$\bar{d}$)
1921	51 (37)	56.1	3.31	(3.64)	5.57	(2.11)
1922	59 (51)	59.3	3.86	(4.21)	5.62	(1.54)
1923	59 (58)	57.5	2.73	(2.74)	4.30	(1.56)
1924	55	60.3	2.24	(2.50)	3.69	(1.18)
1925	56	57.7	3.29	3.94	4.88	0.94
1926	49	59.0	2.55	2.92	3.87	0.95

In commenting upon the results presented in Table 1, it is to be noted that the grain grading specifications call for quotation of dockage in even percentages, all fractions of 1% being dropped in favor of the seller.[4] Hence the mill dockage and total mill screenings, which are calculated to the nearest hundredth of 1% in each case, might be expected *a priori* to be 0.5% higher *on the average*, assuming a large number of samples, than official dockage. Thus, a comparison of assessed dockage with total screenings found might be more properly confined to the determinations of each as determined at the State Testing Mill.

The excess of total screenings over assessed dockage is striking. The actual difference has ranged from 2.11% in the first year (1921) to 0.94% in the 1925 season, giving an average over the six crop seasons (allowing proportional weighting) of 1.34% more screenings as separated by the cleaning machinery of the mill than was assessed as dockage by the officially recognized procedure for determining the same. Thus, ignoring considerations of the disposal as saleable byproducts of the screenings in the mill, the producers have been

[4]Brown (4) regards these fractions of 1% dockage as a "tolerance" in the standards.

credited with considerably more good wheat during the period considered than it has been found feasible with modern milling machinery to convert into desirable flour. This discrepancy found in the case of the Minnesota State Testing Mill, if applied to the entire wheat receipts inspected at the Minneapolis market during the period considered, would represent gains to the sellers and losses to the buyers amounting to 8.4 million bushels of grain. The official "tolerance" of fractions of 1% dockage has been responsible for as much as 1.3 million bushels of this disparity. Thus, probably over 7 million bushels of screenings in excess of this "tolerance" have been classified as good sound wheat in the Minneapolis market alone during the 6-year period.

Opportunity is presented in these data to study the degree of concordance of the two independent series of determinations of dockage on the same samples of wheat. The importance of determining the variability of replicated determinations of this quantity at the hands of any one worker has already been stressed. A comparison of the results obtained by two investigators working independently may throw considerable light on this problem, although care must be exercised in the interpretation of the results to allow for differences in technic which may be involved.

If one variable, on the average, is a linear function of another, the degree of relative concordance of the paired individual determinations which comprise the two variables may be precisely measured by the coefficient of correlation, r. When $r=1$, the correlation between the two variables is perfect, i.e., in the individual measurements of x and y, when one is known the other may be predicted exactly. For zero correlation the other extreme is realized. Values of r between the two limits then indicate the degree of concordance of the individual measures of two variables, which are official dockage and mill dockage in the case under consideration. These coefficients are presented for each crop season in column 3 of Table 2.

TABLE 2.—*Correlation coefficients and approximate prediction range for official and mill dockage.*

Crop season (1)	N (2)	$r_{xy} \pm E_r$ (3)	Range of estimate, % (4)
1921	37	.946±.011	±1.39
1922	51	.909±.016	±1.00
1923	58	.879±.020	±1.41
1924	55	.894±.018	±1.61
1925	56	.967±.006	±1.49
1926	49	.964±.007	±1.54

They indicate a fairly high degree of concordance between the official assessments of dockage and those made subsequently at the State Testing Mill. However, higher coefficients might well have been anticipated. In order to facilitate a mental picture of the association, the scatter diagrams are presented in Fig. 1, wherein each dot represents one carlot of wheat, the dockage assessment according

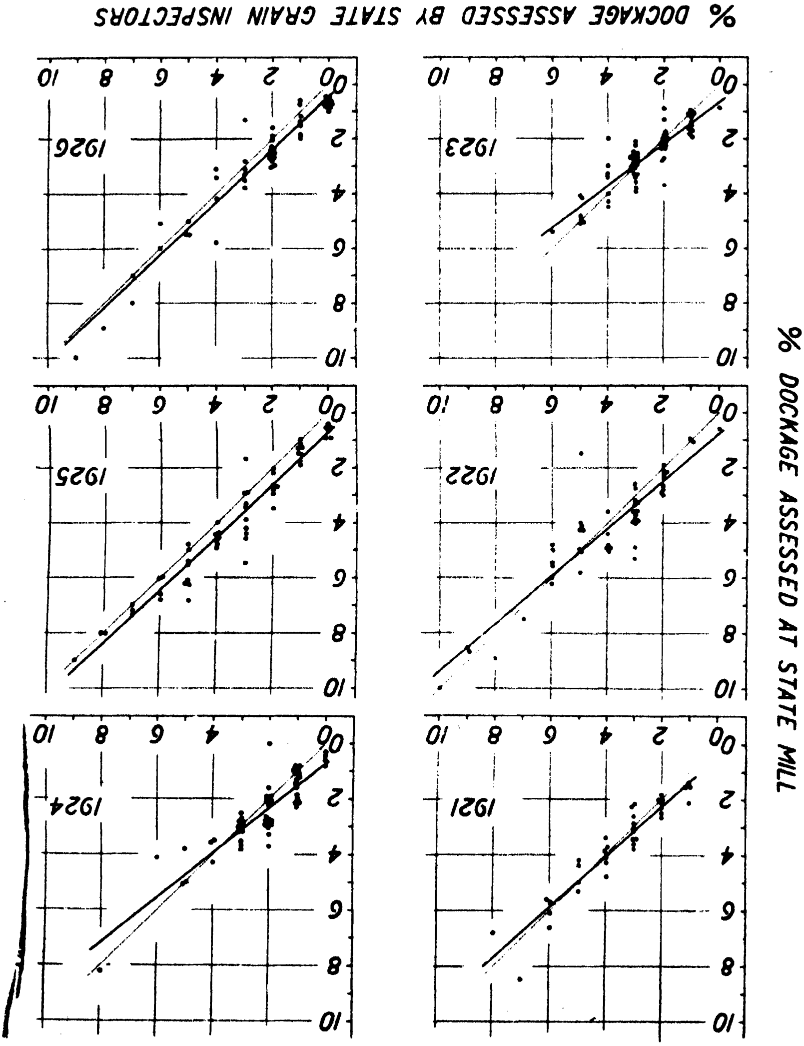

FIG. 1.—Scatter diagram for the correlation between two dockage assessments on cars of hard red spring wheat in six crop seasons. The heavy regression line gives the most likely value of dockage to be expected in the second assessment (at the State Mill) when the official assessment is known. The light diagonal line is that of equality between the two determinations.

to the two analyses being given by the corresponding values on the vertical and horizontal axes. The heavy line through each swarm traces the most likely value of mill dockage to be found associated with each percentage of official dockage. The light diagonal line is that of equivalence between the two dockage estimates.

From Fig. 1 it is quite clear that the two assessments have agreed fairly well on the average, allowing for the expected higher values (+0.5%) for mill dockage for reasons already discussed, but vary from one another in the individual cases over a range the maximum value of which is in excess of 2%. If we may assume that plus and minus deviations of these dots from the regression line is purely a chance one, we may readily calculate the theoretical limits from the regression line within which the cases might be expected to fall if a very large series were available. These limits, ignoring the extreme deviations given by the most discrepant 1% of the sample, are given in column 4 of Table 2. The average range for the 6 years is approximately ±1.5% from the mean, i.e., a large number of wheat samples having the same dockage assessment at the State Grain Inspection Department might be expected to vary over a range of 3% when analysed for dockage at the State Testing Mill. If the official assessments of dockage did not drop the fractions of 1% as called for in the regulations, this range would logically be reduced to 2%.

Assuming similarity of technic by the operators in determining dockage at the State Grain Inspection Department and the State Testing Mill, these figures give a first approximation to the range of replicated dockage assessments from an "average" carlot of wheat by either party. This would indicate duplicate determinations of dockage from the same carlot of wheat might differ by as much as 2% solely through chance, or the errors of random sampling. This value may prove to be somewhat high as an estimate of the range of variation of true replicates, for the assumption of similarity of technic may prove to be a disturbing factor in the results if that is not realized in practise. However, as the most reasonable approximation now available, it must surely challenge the attention of those interested in the reliability of an appeal judgment as opposed to the first assessment and give emphasis to the need for a critical study of the variability of replicate dockage determinations.

The mean values for dockage and total mill screenings given in Table 1 throw considerable light upon the differences between these quantities in several crop seasons, and demonstrate considerable differentiation between the results of assessment from samples and machine screening of the entire bulk. It seems desirable to ascertain whether the average difference between dockage and total screenings

for each crop season is a reasonably constant difference applying to classes of wheat of low, medium, and high content of foreign material, or whether the discrepancy changes in any systematic manner.

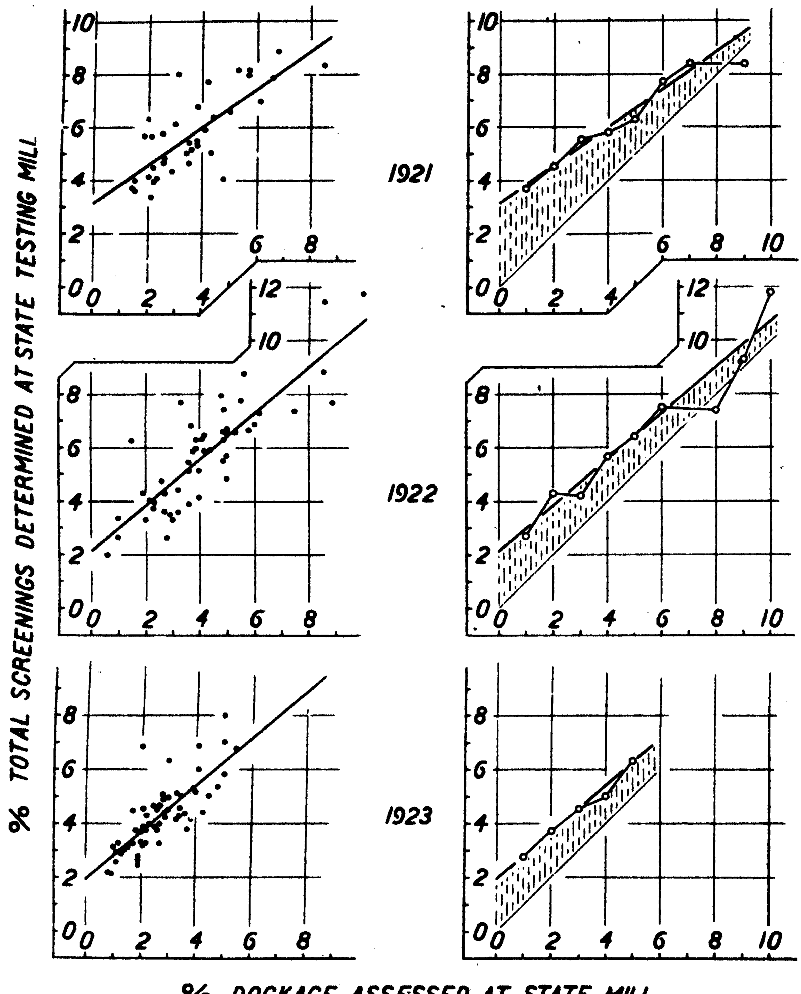

FIG. 2.—Scatter diagram (left) for the correlation between percentage dockage as assessed from a sample and the percentage screenings resulting from commercial cleaning of the entire carlot. On the right, the discrepancy between the regression of total screenings on dockage and equality of the two measures is given by the shaded area. (Hard red spring wheats of the 1921–23 crop seasons.)

Since the two dockage assessments have already been shown to be in essential agreement on the average, it is only necessary to compare one of the two series of dockage analyses with the total mill screenings to obtain a picture applicable to both. Mill dockage will be employed

in the following study since it is recorded on a more comparable basis with the total mill screenings. Again, the relative agreement of the two variables may be measured by the coefficient of correlation, and

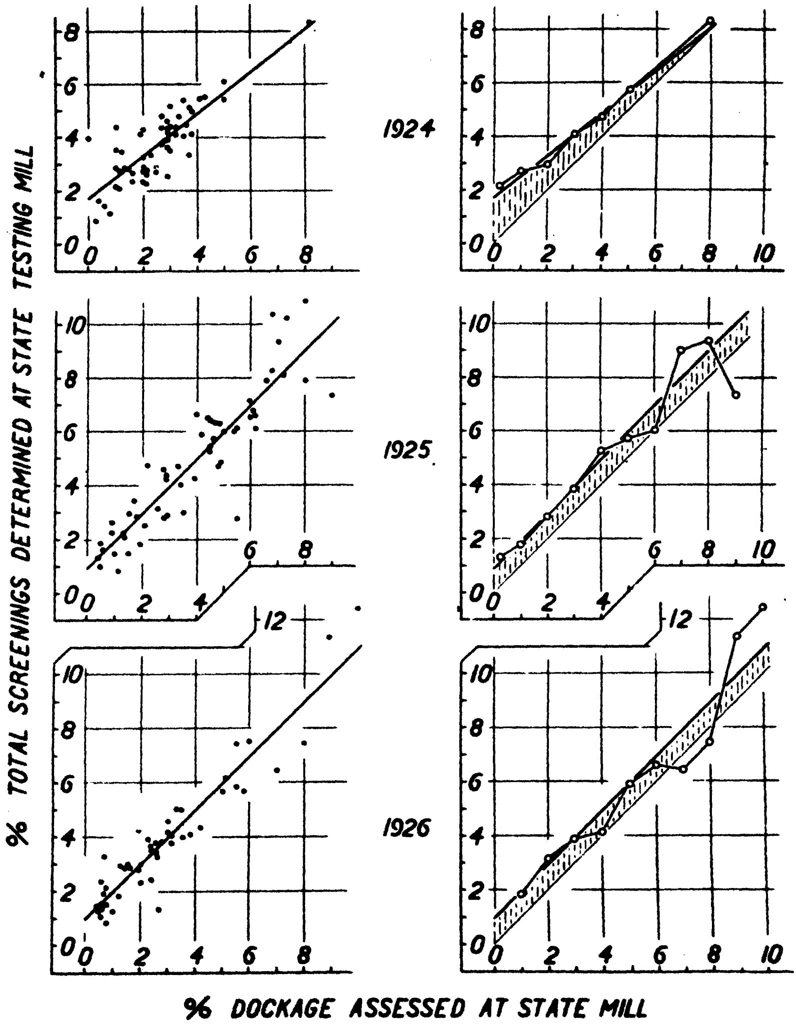

FIG. 3.—Scatter diagram (left) for the correlation between percentage dockage as assessed from a sample and the percentage screenings resulting from commercial cleaning of the entire carlot. On the right, the discrepancy between the regression of total screenings on dockage and equality of the two measures is given by the shaded area. (Hard red spring wheats of the 1924–26 crop seasons.)

the prediction lines (or regression lines of formal statistics) fitted to the full scatter diagrams (Figs. 2 and 3) from the constants thus obtained. The resulting coefficients and prediction equations are given in Table 3.

The total screenings found at the mill are highly related to the dockage estimates. The weighted average value of the correlation coefficient for the entire period is $+.848 \pm .011$. This is a lesser degree of concordance than in the case of the two dockage estimates, but it is still of a high order. The question of whether or not a more perfect relationship should be expected must remain outside of the present discussion. Absolute agreement will, of course, be precluded in practice through errors of random sampling.

TABLE 3.—*Correlation and prediction coefficients for mill dockage and total mill screenings.*

Crop season	N	$r_{sd} \pm E_r$	Prediction equation ($s = K + k\,d$)
1921	37	$+.768 \pm .045$	$s = 3.15 + .71\,d$
1922	51	$+.847 \pm .027$	$s = 2.13 + .86\,d$
1923	58	$+.782 \pm .034$	$s = 1.92 + .87\,d$
1924	55	$+.825 \pm .029$	$s = 1.71 + .79\,d$
1925	56	$+.906 \pm .016$	$s = .91 + 1.01\,d$
1926	49	$+.944 \pm .011$	$s = .96 + 1.00\,d$

The *average* increase of total screenings with unit increase in dockage which has occurred in each crop season is given by the numerical coefficient of d in the prediction equation, where s and d symbolise units of total screenings and dockage, respectively. The constant term, K, represents the most likely percentage of screenings to be found associated in each crop season with zero dockage.

The progressive change of the constants, K and k, in the regression equations from one year to the next is remarkable. The most likely value of total screenings to be found for zero dockage falls steadily from 3.15% in 1921 to 0.91 in 1925, rising slightly in 1926, the rate of increase of total screenings with each unit of dockage showing a decided, though not so regular, rise.

The prediction (or regression) equations summarize the experience for the average relationship between total screenings and dockage for each crop season considered. While they permit the prediction of the *most likely* value of total screenings to be anticipated when the dockage has been estimated, they do not determine exactly the total screenings to be expected for each individual case of dockage except in the ideal case of perfect correlation, i.e., where $r = 1.0$. As r diminishes, the scatter of the individual points about the regression line increases. This will be clear from the left sections of Figs. 2 and 3, which present the full scatter diagrams for the two variables in each year. Each dot on the left sections of Figs. 2 and 3 represents an individual carlot of wheat, while the heavy diagonal line traces

the prediction equation in each season. The right-hand sections of these figures again present the prediction line, but the circles represent the empirical averages of total screenings found associated with each percentage of mill dockage. The agreement between the empirical and theoretical lines is very good in all cases. The light diagonal line is again that of equality between the two variables, the shaded area indicating then the average excess of total screenings over dockage assessed at the mill. Thus, it is possible to illustrate most clearly the discrepancy between the assessed percentage of dockage and the percentage of screenings actually found by machine cleaning of the entire carlots of wheat.

We have no entirely adequate explanation for the progressive change in the nature of the shaded zone from 1921 to 1926. It does seem possible, however, that the effects of increasing wear of the Carter-Mayhew discs in the cleaning machinery, particularly those for fine seed impurities, may have had an important bearing in this matter. However, this remains to be demonstrated.

It might be suggested that the discrepancies between dockage and total screenings illustrated above may be attributed to physical characteristics of the grain itself rather than to extraneous materials. Thus, it was thought that perhaps seasons of low weight per bushel might show a screening loss in the mill of shrivelled and small grain that would be recovered in the sieving and hand-picking practices called for in the official dockage estimation. Again, seasons characterized by a large percentage of cracked grain might show a similar discrepancy between dockage and total screenings. A comparison of the average test weights per bushel given in Table 1 with the average margin of total screenings over dockage for each season fails to support the former suggestion.

The season of 1921 gave shrivelled small hard grain which is reflected in the very low average test weight. The following crop yielded plump heavy grains, while in 1923 the crop was intermediate in character between the two preceding crops, and the following year was plumper and heavier than any of the three preceding it. In the face of these alternating changes in grain plumpness, the change in the regression of total screenings on dockage is perfectly smooth and progressive. Thus seasonal differences do not appear to have had much, if any, influence upon the relationship between total screenings and dockage.

That the amounts of dockage and of total screenings are related to test weight per bushel of cleaned wheat is shown by the coefficients of correlation between these variables presented in Table 4.

TABLE 4.—*Correlations between test weight per bushel and the amount of foreign material in the wheat.*

Crop season	N	Coefficients of correlation	
		Official dockage and test weight	Total screenings and test weight
1921	51	—.281	—.351
1922	59	—.216	—.147
1923	59	—.215	—.122
1924	55	—.256	—.168
1925	56	—.230	—.254
1926	49	—.342	—.318
1921–26	329	—.254±.035	—.222±.035

Plump wheat of high test weight throughout the period considered has apparently shown a consistent tendency to be freer from foreign material than samples containing large amounts of shrivelled grain, i.e., of low test weight. The correlation is not high, but it is reasonably consistent from year to year.

It is desirable to ascertain whether, *within* the crop seasons, there has been any relationship between test weight and total screenings minus dockage for the individual carlots of wheat. In studying this data for the 1921 crop season, Bailey (1) compared the averages of these three variables for the decreasing grades of 1, 3, and 5 dark northern spring wheat. This led to the conclusion that "the difference between dockage and total screenings tends to decrease with increasing grade and test weight per bushel, although the correlation is not exact." The magnitude of any such association between one variable and the difference between two others related to it may readily be measured in terms of the correlation scale. It is clear from these coefficients presented in Table 5 that there was only a slight tendency during the entire period of 6 years considered for any relationship to appear between weight per bushel and the excess of mill screenings over dockage for 329 individual samples of wheat. There is an entire

TABLE 5.—*Correlation between weight per bushel and the difference between total screenings and dockage.*

Crop season	N	Coefficients of correlation
1921	51	+.065±.094
1922	59	+.158±.086
1923	59	+.190±.085
1924	55	+.200±.087
1925	56	—.094±.089
1926	49	+.015±.096
Average 1921–26	329	+.092±0.37

absence of any significant negative relationship. It is evident that the increasing difference between the averages of total screenings and dockage noted by Bailey during the 1921 season for the three grades of wheat considered cannot be attributed to varying plumpness of the grain as measured by weight per bushel. The averages so presented have proved illusory in respect to the relationship on which information was sought.

Thus, the suggestion that carlots of wheat of lower weight per bushel, and hence presumably of a higher content of shrivelled grain, might show a greater screening loss, due to the smaller kernels, than would be recorded in a dockage analysis, is not borne out in fact. Were the data available, it would prove of value to determine the relationship between percentage of broken kernels and the difference between total screenings and dockage. It might possibly prove to be the case that "large pieces of broken kernels" returned to the sound wheat under the dockage assessment methods cannot be fully recovered by the screening machinery of modern milling practice.

DISCUSSION

Evaluation of the equity of dockage assessments must remain outside of the scope of the present work, which has to deal solely with matters of fact. It may be advisable, however, to draw attention to some factors, lack of consideration of which might lead to a misconstruction of issues suggested by the results secured.

Dockage may be determined from two entirely different points of view. The purpose may be to estimate the amount of material other than wheat, be the latter whole or broken, without regard to the losses due to broken or damaged kernels that may be expected in the machine cleaning of the bulk grain before it goes to the break rolls; or, the dockage estimate may be made with a view toward determining, from a composite sample drawn from each carlot, the amount of material present which cannot legitimately or economically be ground into flour for sale as such. If the first point of view be adhered to, then it must remain for the buyers to judge from the proportions of the various fractions of the estimated dockage what the total screenings may be expected to amount to.

Material classed as dockage by the official grain inspectors represents, in form at least, an entire loss to the producer, for grain is always sold on the dockage-free basis. The miller is able, however, to return a part and not infrequently all of the mill screenings to the grinding rolls for feeds, and thus retain them as a tangible asset to his business.

Dockage material should never be regarded by the farmer as a desirable addition to his consignments of wheat, and can very rarely be so viewed by the miller. It seems almost impossible, and probably entirely undesirable, to attempt to give credit to the producer for the amount of such material present, except as the market prices may be able to reflect value in special cases. The dropping of fractions of 1% of dockage in accordance with the official grain standards may be a justifiable leniency toward the producer. It the dockage determination is to be accepted on the trading floor as a measure of that fraction of the wheat shipment which is not suitable or readily available for milling into flour, it seems desirable that assessment of dockage should be adjusted to correspond as closely as possible to the loss by screening machinery which may be expected from the wheat as it passes through the premilling processes.

SUMMARY

The establishment of acceptable standards of variability that may be expected in dockage estimates due to the random (or systematic) errors of sampling cargoes is eminently desirable to meet practical issues of everyday occurrence at terminal markets.

Dockage assessments by official inspectors and the check assessments by mill employees have shown an important deviation below the total screenings secured at the Minnesota State Testing Mill over a period of 6 years. In only 15 cases out of the 329 carlots studied has the determination of total screenings been found less than or equal to the official dockage estimate. The averages for each crop season from 1921 to 1926, inclusive, show that the dockage estimate at the mill, which is higher than the official dockage estimate, has fallen below the percentage total mill screenings by amounts varying from 0.94% to 2.11% screenings. This difference, if applied to all receipts at the Minneapolis market during the same period, would have resulted in gains to the sellers and losses to the buyers of over 8,000,000 bushels of grain, or over 10,000,000 bushels if the "official" dockage estimate be employed.

Two independent dockage estimates considered here, the official estimate, and the mill check have shown a fairly high degree of concordance, which is reflected in correlation coefficients varying between +.88 and +.97 for the 6 seasons. Scatter diagrams show that the range of individual differences is nevertheless quite pronounced, and computations reveal that wheats classified officially as being of the same percentage dockage might be expected to vary over a range

of 3% dockage when checked by an independent worker who retains fractions of 1% in his estimate.

Total screenings cleaned from the wheat by commercial machinery at the mill are fairly highly correlated with the dockage estimate at the mill. The average value of r in this case (+.85) is lower than that between the two dockage estimates. Prediction lines fitted to the scatter diagrams show that for the 1921–24 seasons the discrepancy between dockage estimate and percentage actual screenings was greatest for wheats of low dockage, the difference decreasing as dockage increased in a smooth manner. For the 1925 and 1926 seasons the difference was fairly constant and slightly less than 1%.

Test weight per bushel, measuring relative plumpness of the grain, does not show any clear relationship with the discrepancy found herein between the dockage estimate and the actual percentage of mill screenings.

Assuming similarity of technic in the two independent assessments of dockage considered here, it is possible to present at this time a first estimate of the variability of replicate dockage determinations. Measured in terms of the range of all but the extreme cases (1 in 100), that variability is given as 2% dockage. In the light of these findings, appeal judgments varying up to 2% from the first assessment of dockage should not be considered as differing essentially from the first. Within that range of 2%, the average of the two determinations is likely to be more accurate than either one alone.

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LOCAL, DOMESTIC, AND FOREIGN-GROWN RED CLOVER SEED[1]

R. G. WIGGANS[2]

Red clover was probably introduced into what now constitutes the United States by the early English colonists and has been an important crop throughout the agricultural history of the nation. Its use increased and spread with the development of the country and its production offered no serious problems for decades. The chief reasons for this popularity were (1) its suitability under favorable climatic conditions for growth on fairly well-drained new and rich land, and (2) the home production of seed. In the early agricultural history of this country there was little traffic in red clover seed except the interchanges made locally. However, as the fertility of the soil became depleted and the soil acidity increased, serious difficulties in red clover production were encountered. Many of these have been overcome partly at least by better drainage, improved fertility, application of lime, inoculation, and better cultural conditions, and, in certain cases the elimination of disease and insects. Attention has been more recently called to the importance of particular strains as a factor in successful production of red clover. Attention has been focused on this phase primarily because of increased clover failures regardless of the care exercised in meeting the various specific requirements for success and secondarily because of the advance in our knowledge of inheritance in plants.

More specifically, New York farmers experienced only occasional failures in red clover production 40 to 50 years ago, but after 1900 the percentage of clover failures increased very rapidly and, as a consequence, the production of red clover was materially affected. In fact the condition became so serious that many farmers refused to run the risk of seeding red clover. This same condition was found in other states as well, especially the states next the seaboard and to a less extent in states farther removed from ports and those which were producing more clover seed within their own borders.

The many clover failures, the demand for an explanation of these failures, the importance of the crop as a legume feed for dairy cattle particularly, and its value as a soil builder stimulated many experiments looking for a solution of these problems.

[1]Contribution from the Department of Plant Breeding, Cornell University, Ithaca, N. Y. Published as Paper No. 177 of the Department. Received for publication January 28, 1931.

[2]Assistant Professor.

Almost simultaneously, as a result of tests, several experiment stations and the U. S. Dept. of Agriculture came to the conclusion that many of the red clover failures were due to the use of seed of unadapted strains, the least adapted being seed from southern European countries. Seed from Italy and France was being imported into the United States in large amounts during this period, the bulk of which was consumed in the areas of red clover production which depended almost wholly on outside sources for their seed supply. The well-known red clover seed staining laws resulted directly from the efforts of the U. S. Dept. of Agriculture and indirectly from the work of the various experiment stations. The staining of the imported seed and the information from the experiment stations on suitability of specific lots of seed for use in various regions, coupled with the many failures of farmers, has rather effectively taught the red clover consuming public and the seed distributors that there are strains or varieties of red clover just as truly as there are strains or varieties of any other crop.

The investigators were not satisfied with proving that in general domestic-grown red clover seed is more desirable than imported seed but have gone a step further to prove to their own satisfaction that red clover produced for many succeeding seed generations in a given region is better adapted to that region than red clover grown in any other area differing materially in environmental factors, another proof of the power of open-fertilized plants to adjust themselves to different sets of conditions.

It is upon this last point that the author wishes to present new experimental data following various tests on red clover seed sources conducted during recent years. No attempt was made in this last test to locate the best domestic sort of commercial importance, since Michigan-grown seed had proved as good as any other domestic sort and better than all imported sorts for New York conditions, but an attempt was made to test the Michigan seed against New York-grown seed. An effort was made to find farmers in the state who had produced their own red clover seed continuously for many years. Unfortunately, only four such individuals were located. Lots of seed from these sources were used in the tests, together with one Colorado lot, two from Poland, three from Russia, one from Ukraine, and one from Italy, using Michigan-grown seed for the check plats as in all the previous tests.[3] It was hoped by including seed from northern Europe that some especially hardy lot might be found, as

[3]The seed from Poland and Russia was secured from the U. S. Dept. of Agriculture.

TABLE 1.—*Showing differences between varieties and strains of red clovers and the check plats in dry weight per acre for 1929, Ithaca, N. Y.**

Variety or strain	First cutting				Second cutting				Season's total†
	Series 1	Series 2	Series 3	Average	Series 1	Series 2	Series 3	Average	
New York No. 1	2	222	71	98±44	162	426	275	288±52	386±95
New York No. 2	—500	—446	—366	—437±26	—223	—222	—248	—231±6	—668±21
New York No. 3	—29	2	6	—7±7	—17	173	44	67±38	60±43
New York No. 4	660	474	518	551±38	—1,788	—1,873	—1,816	—1,826±17	—1,275±53
Poland, 15696	—630	—291	—484	—468±66	—569	—834	—698	—700±52	—1,168±15
Poland, 15517	—647	—176	—386	—403±92	—632	—848	—720	—733±42	—1,136±51
Russia, 15525	—653	—284	—648	—528±82	—668	—960	—814	—814±57	—1,342±43
Russia, 15710	—479	—344	—526	—450±37	—539	—827	—568	—645±62	—1,095±30
Amtorg Trading Corp.	—483	39	—429	—291±112	—1,959	—1,980	—1,875	—1,938±22	—2,229±101
Ukraine, 15703	—728	—182	—425	—445±107	—2,133	—2,248	—2,060	—2,147±37	—2,592±91
Italian	—2,164	—2,410	—2,112	—2,229±62	—1,668	—2,146	—1,323	—1,712±161	—3,941±221
Colorado	277	298	200	258±20	35	6	24	22±6	280±19

*Mean of all checks (Michigan-grown seed) = 3850±36 pounds of dry weight per acre, 1st cutting.
Mean of all checks (Michigan-grown seed) = 3034±39 pounds of dry weight per acre, 2d cutting.
6884±53 pounds of dry weight per acre, season's total.

†The probable errors were derived from the season's totals of the three individual series.

seed from the extreme northern regions had not been included in previous tests.

The results of this test are given in Table 1. These data show in dry weight yields per acre the differences between the check plats and the various plats produced from seed of other sources. The plan of the test was the same as that previously used, namely, long narrow plats (8 x 100 feet) with a check every third plat and 8-inch alleyways between plats.

The interesting points in Table 1 are as follows: (1) The four New York lots were very different from each other. New York No. 3 was very similar to the check, New York No. 4 was obviously a single-cut clover, New York No. 1 for the season of 1929 was better than the check in the second cutting, and New York No. 2 was only slightly better than imported seed. (2) All imported lots were much inferior to the check and two of them were single-cut clovers. (3) The Italian seed was far inferior even in an excellent clover year. (4) The Colorado seed produced better in the first cutting and as well in the second cutting as the check.

One year's test cannot prove the superiority of any given strain, but with the evidence from the many previous tests more weight can be given to the 1929 results. However, one conclusion can be very specifically drawn, namely, that definite strains of red clover do exist even in a limited area and that efforts should be made by the investigator to locate the best in existence for the given area.

LENGTH OF LIFE OF RED CLOVER PLANTS

The length of life of the red clover plant has often been discussed and the data in Table 2 are given to show that some plants live through the second winter but that the majority fail to survive. These observations were made because of the statement that red clover plants which are living the second spring after seeding are seedlings of the second summer and not old plants which survive two winters. The yields of the checks as given in Table 1 show that the season of 1929 was an excellent clover year. In the fall of that year practically a perfect stand of clover was present and it was decided to let it stand for a second season's crop provided it could survive the winter. One previous test, 1924–26,[4] had given a fair second season's crop. Careful notes were taken on the condition of the stand and individual plants in the fall of 1929 and again in the spring of 1930 after a severe winter resulting in a large amount of heaving. Many individual plants which were without doubt one

[4]Cornell Univ. Agr. Exp. Sta. Bul. 463. 1928.

year old, having already produced two good cuttings of hay, were carefully tagged in the fall and observed in the spring. In fact new seedlings were carefully sought, but observations revealed no plants which could be identified positively as 1929 seedlings. This was to be expected since germination tests of the various lots of seed before the test was sown showed the presence of very few hard seed. The fact that no 1929 seedlings could be identified made it certain that plants surviving the winter of 1929–30 were two-year-old plants.

In the spring of 1930 the individually tagged plants were studied and certain ones were found to have survived. The numbers were rather small for determining the percentage so a different method was employed in view of the fact that practically all living plants which went into the winter of 1929–30 were old plants. Areas 2 feet by 2 feet at three different locations in the various plats were laid out in systematic order similar to the plan followed in taking shrinkage samples. This method was employed in order to avoid any personal factor of selection. Within these areas all established plants were counted. All the clover plants which were present in the fall were still present in the spring. These were grouped into three classes, *viz.*, dead, doubtful, and vigorous. The doubtful group was largely made up of plants which survived but which were in such weakened condition that their production would be very small. The data are given in Table 2 and are expressed both in the average number of plants per 4 square feet and in percentages.

The results in the table show (1) that certain red clover plants live over the second winter even though severe, and would if permitted to do so produce a fair crop as individual plants the second season; (2) that following a severe second winter too few plants survive to be of any economic value for crop production; (3) that the differences between strains in their ability to survive the second winter are not sufficiently great to be studied following severe winters; and (4) that there is an indication that the New York strains are hardier than the check and that some lots from extremely northern environments in Europe survive even better than the native lots.

DRY WEIGHT DETERMINATIONS IN RED CLOVER TESTS

Various methods have been used in red clover tests to determine the relative yields. Some have been based on green weights only, some calculated to a dry weight basis by assuming a particular percentage dry weight, some have been based on weights of field-cured material, some on air-dried samples, and some on kiln-dried samples. Such variation in methods causes considerable error and makes compar-

TABLE 2.—*Number and condition of stand at the beginning of the second crop year, May 8 to 9, 1930.**

Strain of clover	No. of clover plants per 4 sq. ft.				Percentage of clover plants			Weeds and grass	
	Total	Dead	Doubtful	Vigorous	Dead	Doubtful	Vigorous	No.	Percentage of total
Aver. of all checks	49.9	44.1	5.2	0.6	88.4	10.4	1.2	4.1	7.6
New York No. 1	39.6	31.3	6.8	1.5	79.0	17.2	3.8	1.7	4.1
New York No. 2	40.0	31.0	7.3	1.7	77.5	18.2	4.3	2.2	5.2
New York No. 3	28.2	26.2	1.7	0.3	92.9	6.0	1.1	6.5	18.7
New York No. 4	26.5	20.5	5.5	0.5	77.4	20.7	1.9	2.0	7.0
Poland 15696	34.4	28.3	5.3	0.8	82.3	15.4	2.3	2.8	7.5
Poland 15517	29.0	28.2	0.8	0.0	97.2	2.8	0.0	5.8	16.7
Russia 15525	37.0	32.8	2.0	2.2	88.7	5.4	5.9	3.3	8.2
Russia 15710	38.8	36.3	2.3	0.2	93.6	5.9	0.5	2.0	4.9
Amtorg Trading Corp	34.3	26.8	7.2	0.3	78.1	21.0	0.9	7.7	18.3
Ukraine 15703	31.2	21.7	7.3	2.2	69.6	23.4	7.0	10.8	25.7
Italian	5.5	5.5	0.0	0.0	100.0	0.0	0.0	9.2	62.6
Colorado	39.1	31.3	7.3	0.5	80.0	18.7	1.3	1.2	3.0
Average	33.3	28.0	4.5	0.8	85.0	12.7	2.3	4.6	14.6

*Data based on counts of plants in areas of 2 x 2 feet at three different areas in all plats of two series.

isons difficult. The data in Table 3 are presented as an argument for the kiln-dry method for the determination of dry weight yields as a reliable procedure.

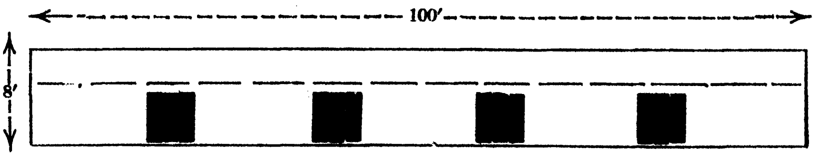
The method employed in this and previous tests at Cornell is to take the green weight of the entire plat immediately after it is cut before any appreciable loss can possibly occur. This is accomplished by mowing in one direction and cleaning up a swath at a time. The first swath is placed on the weighing rack before the second is cut. In no case does the cut material remain in place as long as 5 minutes. If necessary, two weights per plat are taken, but ordinarily one is sufficient.

TABLE 3.—*Percentage dry weights of clover varieties, 1929.*

Variety	1st cutting	2d cutting
Checks (Michigan seed)	19.45±.13	21.17±.12
New York No. 1	18.99±.41	21.16±.07
New York No. 2	19.09±.15	20.60±.05
New York No. 3	19.39±.19	21.18±.40
New York No. 4	17.54±.10	18.00±.05
Poland 15696	20.27±.37	20.72±.07
Poland 15517	20.16±.24	20.92±.39
Russia 15525	19.54±.41	20.71±.34
Russia 15710	19.90±.16	21.50±.47
Amtorg Trading Corp	17.88±.18	19.11±.75
Ukraine 15703	17.32±.33	19.12—*
Italian	20.14±.36	22.38—*
Colorado	19.71±.21	21.43—*

*Only one series sampled.

The shrinkage sample is taken from the first swath of the plat from four different areas according to the accompanying diagram:



One man is charged with taking all the samples. He endeavors to get about 5-pound samples from each of the four areas of the plat, securing a minimum of 20 pounds for a sample. He follows the mower very closely, and as soon as the sample is assembled it is placed in a burlap bag and the net weight taken. This is done while the rest of the working force is gathering and weighing the bulk material from the plat. If this procedure is followed, from 10 to 15 plats can be harvested in 1 hour with six men. No effort is made to scatter the green material until the harvesting is done or until the next morning when the dew is on before harvest can begin.

At the end of a half or full day's harvest the weighed, bagged, and tagged shrinkage samples are taken to the dryer, removed from the bags, and spread out in the trays. This material may then be kiln dried at any time. If the drying is not done immediately the samples will require a few turnings to permit air circulation and to prevent molding.

Only one sample is taken from each plat as past experience has shown that two samples carefully taken from the same plat check very closely. Samples are taken from at least two series of plats and the average of the samples used in calculation of the dry weight yields of the areas. Attention is called to the small probable errors attached to the percentage dry weight figures in Table 2; likewise, the variation from one strain to another and the large error which would be introduced in the comparisons of the yields if they were made on any other than the dry weight basis. A difference of 1% in the percentage dry weights is in most cases statistically significant.

CONCLUSION

The test reported above gives added evidence to the following conclusions:

1. There are distinct strains of red clover produced not only in widely separated regions of diverse environmental conditions, but also within regions differing only slightly in the various factors.

2. Investigations up to the present time have not exhausted the possibilities of the discovery of adapted strains of red clover for various regions.

3. Even though clover seed happens to have been produced in a given area for several seed generations, this is no absolute guarantee that it is the best strain for that region, however true it may be as a general principle.

4. The best method of making comparisons between strains of red clover (and other forage crops) is on the dry weight basis, the dry weight percentage having been determined from carefully taken and artificially dried shrinkage samples.

5. Red clover plants survive the second winter with difficulty, but there is no question that some plants live longer than one season.

6. Red clover strains differ in their length of life and ability to survive severe winters due to their hereditary make up.

NOTES

EROSION

During the past several years, increasing attention has been given to the study of soil erosion in the United States. Detailed research into the erosion resulting from cultivation, from burning the vegetation, from the removal of the timber cover, from farm pasturing, and from heavy grazing in the western arid and semi-arid states is rapidly getting under way.

It is highly interesting to find that studies are also being made in some of the lesser-known countries of other continents than North America. The following is a literal translation of an article in *la Depache* of September 30, 1930 in Constantine, Algeria. The newspaper is printed in the French language, with occasional Algerian idioms.

EROSION AND HOMESTEADING

Following a general study on reclaiming hillsides, an Algerian reminds us that there are many pieces of land collectively called "archs" (hillsides exceeding 33%). In order to obtain a deed to individual property, it is necessary first to clear it and thus one offers it to erosion! The giving of a deed for individual property has evidently only good social effects, the settling of the farmer and the establishing of a home, with the resultant land improvements which one makes only on his own property. The clearing of land permits the farmer to increase the land under cultivation, which is usually begun on the plains. But it seems that no regulation has seen fit to limit these clearings for the maintenance of the original top soil. It appears that between the clearing of the land and handing over of a deed of individual property, 5 to 8 years pass. In the meantime, erosion does its work and the title holder finds himself faced by a slope cut by ravines where bare rock replaces the bushes! The fertility of the land has gone away to the bottom of the river!

There are landslides, sometimes as much as 2.47 acres at the foot of the barren slope; a field of mud in winter, a field of cracks, crevices, or hard lumps in summer. Dwarf palms have been succeeded by sterility. It costs more to stop erosion than to clear pasture land. The cultivation process finishes by sheep again pasturing on the land.

Following the Algerian floods of 1927, the Forest Commission cited land clearing as a frequent cause of erosion and as the principal cause of the carrying along of silt which fills up the dams and reservoirs, rendering them useless after having been used only a very short time. In the headlands of the Perregaux, the basin of the el Hamman River is made up of lands having impervious soils, made barren by cultivation or by abusive use of the pasture lands by herds. The slopes being almost always extreme, erosion takes place rapidly and this region (the lowlands of Tizi) constitutes definitely the principal source of silting, the materials of which, deposited from the headlands of the dam to beyond the Perregaux, have increased noticeably the disasters due to floods. It will be necessary to seek a remedy for floods by increasing the absorbing power of the forests and by stopping definitely the clearings of the slopes.

The village of Bou Henni is flooded and silted periodically by overflowing of Cabet Yalou. The susceptibility to torrents of the ravines, which were unknown 20 years ago, is due to erosion caused by the land clearings carried on since that

time, by putting the land into cultivation and by the abuses of the common pasture land. At Rivoli the canals and the ditches have been filled with deposits coming from the cultivated slopes and from the vineyards in Pliocene sand-stone soil. Their unstable condition, due to the plowing, permits them to be washed away, even on gentle slopes such as in the neighborhood of Mostaganem, Ouilli and Bosquet. The Commission proposes to stop cultivation and to replant the lands to the original native shrubs, as well as to re-forest the potential timberlands. In the basin of the Krasmus River around Renault, the upper valleys are clay and the forest is similarly encroached upon by cultivation.

If the damages have been less in the valleys bordering the sea by the Krasmus River and the Ténés, it is because this unpopulated region has remained wooded. Man is the enemy of the forests. It would be better to organize them into wooded estates under a title of protection rather than keep them in a state of which will one day cause the land to be exhausted under cultivation. There would be opportunity also to intervene in behalf of the new farmers of Guelta, Marsa, and Pointo-Rouge, whose instructions impose the obligation of clearing the land up to the summits of the hills.***

Instead of ordering thoughtless clearing and even of subsidizing it, they will forbid it on the slopes which are too steep, on the grades on slopes of clay or siliceous soil exceeding a certain degree. As a last resort, lands mistakenly cleared may be replanted, with limitations, or used for the pasturing of sheep and especially of goats. When the herds belong to the same proprietor as the land on which they graze, the future will be better assured. In America, also, one notices abuses of clearings and an experimental erosion station has just been created in Utah. It is a question of determining in what measure the tendency to erosion must limit cultivation. They will see then how to avoid erosion on cleared lands. Instead of having burdensome terraces in Ceylon, they tend to dig ribbon trenches and keep trimmed the bushes on the slopes where they plant tea trees. A new technic limits cultivation by the plow.

The conditions in those parts of Algeria described above appear somewhat similar to those which prevail in parts of northern Mexico and, to a lesser extent, in sections of southwestern United States. Strikingly comparable results from much of the homesteading of our western states exist today in this country. In a recent article by Bennett[1] detailing the destruction of lands in many parts of the United States, the same story is told repeatedly, only with different settings within the United States. The problem is apparently worldwide, excepting in the polar regions of the earth.—W. A. ROCKIE, *Pacific Northwest Soil Erosion Experiment Station, Pullman, Wash.*

TEXAS LEGISLATES FOR SOIL CONSERVATION

The Forty-second Texas Legislature recently has passed one bill and three resolutions relating to soil conservation. The bill, which passed The House and the Senate and was signed by the Governor in April, recognizes that soil erosion is the greatest menace to the agricultural lands of the state, and authorizes the employment of county and state road machinery, while not in use on the roads, for constructing terraces on privately owned lands.

House Concurrent Resolution No. 45, reads in part as follows:

[1] BENNETT, H. H. Erosion. Country Gentleman, 101: No. 5, 10. 1931.

"WHEREAS, We recognize the preservation of the fertility and productive capacity of our agricultural lands as our greatest conservation problem and responsibility; therefore be it

Resolved: by the Legislature of Texas, That we commend the progressive policy of the United States Department of Agriculture in its scientific research into the grave problem that confronts the country in land erosion and soil impoverishment, and the influence of these conditions upon the economic welfare of agriculture; and urge upon the Department the continuation of its investigations in Texas in the manner inaugurated, for the development of useful and necessary information for the extension of effective efforts for soil and moisture conservation and the protection of the whole agricultural industry."

A second resolution passed and approved in April has the following to say:

"WHEREAS, it is important that public attention be directed to the necessity for the conservation of soil fertility for the public benefit, and a warning be given as to the damages from erosion of the soil by surface waters left uncontrolled:

Now, Therefore, be it Resolved, That the second week in January be, and is hereby declared "Soil and Water Conservation week in the State of Texas" and fifteen days prior to which time, the Governor of the State shall issue his proclamation declaring the second week in January to be soil and water conservation week, and call upon all citizens to take note of the condition of the lands owned by them and to confer with the County authorities and particularly their Commissioners' court, County Agent, and Vocational Teachers with regard to ways and means of giving proper protection to soil which is being damaged from erosion and lost to the owners and posterity for the lack of adequate protection by terracing and drainage."

The third resolution passed and approved in May is as follows:

"WHEREAS, The Forty-Second Legislature has recognized that soil erosion is the greatest and most constant menace to continued productive agriculture in this State, and

WHEREAS, The greatest and most satisfactory measures of preventing this loss of our natural resources depends upon the cooperation of all agencies in this State, and

WHEREAS, Financial institutions, making loans for the re-financing of farms or for the purchase of lands; or for crop production, are in a position to become one of the greatest factors in the development of a permanent agriculture, through urging and encouraging the conservation of soil and water, and

WHEREAS, The American Society of Agronomy and the Southwestern States Soil and Water Conservation Conference have requested that all financial institutions, making loans to farmers, join in the soil and water conservation program,

Therefore, be it Resolved, That the Forty-Second Legislature urge and insist that all farm mortgage institutions, making loans for land purchase, and re-finance of farms, and all local banks and other farm credit agencies, making loans for crop production, join in the State Conservation program to the end that our soils may be conserved and that moisture be controlled, and fertility maintained and restored by terracing, and by the adoption of proper cropping systems, and intelligent methods of soil management.

Be it Further Resolved, That the Chairman of the State Soil and Water Conservation Committee notify the lending agencies of this action, and that the State

Committee on Soil and Water Conservation assist such agencies in formulating a program conforming to, and supplementing the already existing State Program of Soil and Water Conservation.—H. H. BENNETT, *Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C.*

BOOK REVIEWS

PRINCIPLES OF AGROBIOLOGY OR THE LAWS OF PLANT GROWTH IN RELATION TO CROP PRODUCTION

By Oswin W. Willcox. New York: Palmer Publishing Corporation, 96 pages, illus., 1930. $4.

Agronomists who have been embarrassed by an oft-stated opinion that "agronomy is not a science" may now be relieved by adopting the title of "Agrobiologist." In the book here reviewed, the author himself admits that he has made "provision, for the first time, of the basis for a genuinely scientific agriculture depending on a coordination of the knowledge of the laws of plant growth in relation to the unit area of land surface." The above quotation is one of nine "original features" included in the copyright of the book. This copyright may or may not prohibit other agrobiologists or agronomists from publishing statements regarding growth factors affecting acre yields of crops.

According to the author, "Agrobiology is that division of Agricultural Science which considers the general external relations of crop plants to their environments, and their mass reactions to growth factors." How agrobiology differs from crop ecology is not stated. He says "agrobiology need not be confused with what is known as agronomy. The functions of an agronomist are distinguishable from those of an agrobiologist, although every really successful farmer must be both an able agronomist and a competent agrobiologist.—— The sugar cane agrobiologist, for example, is primarily concerned with identifying and reproducing the conditions that will lead to the production of maximum crops of cane and sugar per unit of land surface. But the sugar cane agronomist—as such— is primarily interested in neither cane nor sugar; his main object is to earn maximum dividends on the capital invested in the plantation."

The reviewer, and perhaps many other agronomists, has believed that an agronomist is primarily concerned with crop production, and that one whose object is to earn maximum dividends on the capital invested is an economist. The author rules otherwise.

In Part I of the book, the ten primary laws of agrobiology are listed and defined. The author states, "The laws themselves require no proof; their authority is self-evident from their mere statement to any person having an acquaintance with plant growth." These laws are mostly more or less arbitrary statements of known facts regarding crop production with reference to heredity, plant nutrition, and growth factors, including restatements of "Liebig's Law of the Minimum" and the Law of Diminishing Increments. Law 10 and the discussion and formulae following it describe the typical sigmoid growth curve.

Part II discusses "The General Law of Growth Factors and Its Derivatives," including the application of the Mitscherlich and Spillman formulae in the fitting of curves to the yield data from varying quantities of fertilizer applications. A formula also is presented for determining the theoretical maximum possible yield which can be obtained from any given crop of which the nitrogen content is known. This formula is based upon the average nitrogen content of the crop and a fixed theoretical limit of 3.6 metric quintals per hectare (321 pounds per acre) as the maximum quantity of nitrogen which any crop can absorb during one growth cycle. On this basis the maximum possible (perultimate) yields in bushels per acre are calculated as follows: corn 225, wheat 171, potatoes 1,330, and oats 395.

Part III contains a brief discussion of "Fertilizer Statics", and Part IV is a mathematical appendix.

The book doubtless could have been improved by a more adequate criticism of the manuscript, and readers doubtless would be less critical of the book if the author had not, on the opening page, apparently made dogmatic claims of certain well-known facts as original features which he has copyrighted.

Probably the most useful portions of the book are those dealing with the "law of diminishing increments of yield," and other theoretical and mathematical considerations related to this law. On the whole, the book is a laudable attempt to show that crop growth is an orderly process depending upon natural laws. Numerous selected examples from field experiments, chiefly with sugar cane and sugar beets, are presented to show how crops obey the laws of plant growth. It is well worth reading by all critical students and investigators in the field of plant introduction. (J. H. M.)

THE PHYSICAL PROPERTIES OF THE SOIL

By B. A. Keen. New York: Longmans, Green & Co. 380 pages, illus. 1931. $8.

Workers in this field have been looking forward to the appearance of this book ever since its preparation was announced several years ago. There has been much research on the physical properties of the soil in the last three decades, but this is the only book on the subject in the English language since that of Warington published in 1900. The author has been an outstanding leader in this field ever since his connection with the Rothamsted Experiment Station as Soil Physicist.

A good idea of the scope of subject matter treated can be obtained from the chapter headings, as follows: I. Historical Introduction; II. Mechanical Analysis; III. Distribution and Movement of Water in the Soil; IV. Soil Properties at Low Moisture Contents: The Field Range; V. Soil and Clay Pastes and Their Beheavior; VI. The Properties of Soil and Clay Suspensions; VII. Soil Constants and Equilibrium Points; VIII. Physical Properties of Soil under Field Conditions: Cultivation and Cultivation Implements; IX. Soil Temperature; and X. The Soil Atmosphere.

The chapter on mechanical analysis forms an excellent introduction to the subject. All of the methods in common use for the

determination of size distribution are discussed in a clear, concise, and logical way. A description is given of the Keen-Oden automatic recording balance, although the author points out that no way has yet been found for circumventing the error due to currents set up as a result of density changes in the liquid under the pan. No mention is made of recent developments in the use of the centrifuge for determining the size distribution of particles too small to settle out by gravity alone in a reasonable period.

The author has long been interested in soil-soil moisture relationships and consequently this subject is handled in as satisfactory way as any one could do it. The book would be worth while if there were nothing in it but a summary of the work done in the Rothamsted laboratories. An examination of the bibliography of 263 references shows, however, that the available literature has been carefully analyzed. It is a book that no one interested in the subject can afford to be without. (R. B.)

AGRONOMIC AFFAIRS

FILM-STRIP PRICES

The United States Department of Agriculture announces that the same low prices for film strips will prevail during the fiscal year 1931–32 as have been in effect during the past three years.

Prices will range from 35 to 71 cents each, depending upon the number of illustrations in the series. The majority of the 120 series that the Department has available will sell for 35 and 44 cents each. Film strips are available on such subjects as farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, farm economics, farm engineering, home economics, and adult and junior extension work. Lecture notes are provided with each film strip purchased.

The popularity of film strips among extension workers, teachers, and others has been due primarily to the reasonable prices charged for them, the convenience with which they can be handled, and their effectiveness in educational work. A list of available film strips and instructions on how to purchase them may be obtained by writing to the Office of Cooperative Extension Work, U. S. Dept. of Agriculture, Washington, D. C.

THE ANNUAL MEETING

At the twenty-fourth annual meeting of the Society to be held November 19 and 20 at the Stevens Hotel in Chicago, the Friday afternoon session will be open to the presentation of papers submitted by members of the Society. Any member of the Society may present a paper at that time, providing the title is submitted to Dr. P. E. Brown, Secretary, not later than October 1, together with a statement of the time required to present the paper and an abstract of not more than 200 words.

The opening session at the meeting will be devoted to the transaction of the business of the Society, while at later sessions symposia

will be presented on cold and drought resistance in plants, on soil organic matter and soil classification, on the relation of calcium and magnesium compounds to soil conditions and plant growth, and on soybeans.

Printed abstracts of all papers are to be made available prior to the meeting.

NEWS ITEMS

THE SEVENTH annual Soil and Land Valuation Short Course was held at Iowa State College, May 6 and 7, 1931, with a registration of 115. Most of the insurance and mortgage companies and land banks interested in loans on Iowa farm land were represented. The first program for the first day consisted of addresses and discussions of soil management principles, business methods in farming, and the farm credit situation. The second day was devoted to a 165-mile tour through parts of the Wisconsin Drift, Iowan Drift, and Mississippi Loess soil areas in northern central Iowa to observe glacial, loessial, peat, and muck soils and alkali.

ROY T. KIRKPATRICK has resumed his duties as assistant professor of field crops at the University of Missouri after a year's leave of absence to do graduate work at the Iowa State College.

DR. HANNS KELLER, international exchange student from Vienna, Austria, who has been doing special research work in Soils at Iowa State College during the past year, has completed his work and will spend the summer in Colorado and other western states studying soils in the arid regions. From there he will return home, going by way of Spain and southern France where he plans to spend some time studying soil types and profiles. Dr. Keller is research assistant to Professor Kaserer of the Department of Farm Crops and Soils at the Hochschule für Bodenkultur, at Vienna.

DR. ROBERT EVANS, head of the Department of Agronomy and chief agronomist at the Utah State College of Agriculture and Experiment Station, spent the second week in June at Iowa State College looking over the experimental work and reviewing the projects under way in the Department of Farm Crops and Soils.

E. R. HENSON, assistant professor of farm crops at the Iowa State College, received the Ph.D. degree from that institution in March.

The Department of Farm Crops and Soils at Iowa State College held a short course for hail adjusters on June 19 and 20. There was an attendance of 135 hail adjusters and insurance officials from Iowa and the neighboring states.

The seedsmen's short course annually offered by the department of Farm Crops and Soils at the Iowa State College was held this year on June 15 and 16, with 50 seedsmen in attendance.

S. C. SALMON has resigned as professor of farm crops, Department of Agronomy, Kansas State College, to accept a position as principal agronomist in the Office of Cereal Crops and Diseases of the U. S. Dept. of Agriculture, effective July 1. Professor Salmon has been with the Kansas institution since 1913 and has been professor of farm crops since 1917.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 AUGUST, 1931 No. 8

THE NATURE OF SOIL BUFFER ACTION[1]

L. D. BAVER[2]

Studies relating to the determination of the amount and nature of soil acidity have shown that different soils, when treated with an acid or base, vary in their resistance to changes in H-ion concentration. Soils with a relatively high resistance to changes in their pH values have been termed "well-buffered." They have also been referred to as possessing "high buffer capacities or properties" or as containing considerable quantities of "buffering constituents." Soils with considerable amounts of clay or organic matter have always exhibited stronger "buffer properties" than those with smaller quantities of these materials. Although most experimental observations have shown that the buffering properties of soils are associated with the colloidal material, there are several divergent interpretations of the nature of this buffer action which need to be clarified.

It is the purpose of this paper to discuss (a) the nature of soil buffer action as affected by various soil constituents and (b) expressions for the evaluation of the buffer capacity of soils.

CONCEPTS OF SOIL BUFFER ACTION

Various explanations of the nature of buffer action in soils have been given by different investigators. Only several of the more outstanding of these explanations will be discussed in this paper. A more complete discussion of the literature on the buffer capacity of soils is given in an excellent paper by Maiwald (12).[3]

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the permission of the Director. Received for publication February 26, 1931.

[2]Formerly Associate Soil Chemist, Alabama Experiment Station; now Assistant Professor of Soils, University of Missouri, Columbia, Mo.

[3]Reference by number is to "Literature Cited," p. 605.

Bradfield (4), in his explanation of the nature of soil acidity, states that the well-established fact that the buffer action of soils is directly proportional to their colloid content is exactly what should be expected if their acidity is due to acids of colloidal dimensions. Buffer action in soils is considered a result of the dissociation phenomena of these weak colloidal alumino-silicic acids and their salts.

Kappen (11) suggests that buffering in soils may be due to three different processes, as follows:

1. Dissociation phenomena similar to that in a mixture of a weak acid and its salts, such as acetic acid and sodium acetate.
2. Binding of acids and bases by amphoteric compounds.
3. Adsorption of acids and bases from solution.

He considers the third process as being predominantly responsible for soil buffer action, removing H and OH ions from solution similar to a straight neutralization process. In the acidulation of an alkaline soil several different processes are involved which remove H and OH ions from solution. In the first place, the H ions of the added acid react with the OH ions from the hydrolysis of carbonates. After the disappearance of OH ions, the soil acts buffered due to dissociation phenomena between the free carbonic acid and bicarbonate. Further acidifying causes the humates and zeolitic silicates to produce buffer action by replacement of the Ca and Mg ions with H ions, resulting in the formation of difficultly-soluble clay and humic acids. The addition of more acid increases the buffer capacity due to the formation of aluminum salts through the partial destruction of the silicate complex.

In the addition of a base to acid soils, Kappen considers the process as being a straight neutralization with the formation of a salt with the insoluble clay and humic acids. It is considered unnecessary to think of this process as an ion exchange between the cations of the base and the H ions of the zeolitic silicates. He states that there is a direct reaction between the H ions on the solid phase and the OH ions entering into it whereby the place occupied by the H ions is directly taken by the cations of the base. This is similar to a simple neutralization reaction as

$$Ca_2(HPO_4)_2 + Ca(OH)_2 \rightleftharpoons Ca_3(PO_4)_2 + 2\,H_2O \quad (1)$$

Hydrogen ions that are replaceable by metallic cations are said to be present in neutral or alkaline reacting silicates. If the silicates take up base after complete saturation, however, straight adsorption occurs. This adsorption has no practical application to the buffering capacity of soils.

Kappen summarizes his views by stating that the same chemical substances determine the reaction of the soil on one side and the resistance to change in reaction on the other. These constituents are calcium carbonate or bicarbonate and carbonic acid, the humates and zeolitic silicates, and finally the salts of aluminum.

Wéigner and Gessner (17), on the basis of the investigations of Jenny (8), attribute the rôle of buffer action in soils to calcium carbonate, humus, and clay. Humus is strongly buffered towards bases and weakly towards acids. Clay is strongly buffered towards acids and weakly towards bases. The exchange of H ions is considered the cause of the buffer action in humus and clays.

Behrens (3) associates the buffering properties of the soil to small amounts of acid with the formation of colloidal acids and their salts. The reaction of the soil suspension is dependent upon the equation

$$(H^+) = K \cdot \frac{C_{\text{permutite acid}}}{C_{\text{permutite salts}}} \cdot \frac{S}{1-S} \qquad (2)$$

where S is the amount of acid added and C represents the concentrations of the permutite acids and their salts. The presence of the permutite salt represses the ionization of the H-permutite. Maximum buffer action occurs at the pH value equivalent to the pK value of the acid. Increased acid additions cause a dissolution of the aluminosilicate complex according to the equation

$$\text{H-permutite} + 6H^+ = 3H_2SiO_3 + 2Al + H_2O \qquad (3)$$

This process takes place to a great extent only below pH 3.0. After calculating the effect of the aluminum, the buffer curves were found to be similar to those of dibasic acids.

Maiwald (12), from a study of the factors affecting the titration curves of soils, comes to the conclusion that the soil has the ability to act as a buffer to reaction changes through its colloidal complex capable of ionic exchange. This action is similar to that of a very heterogeneous acid-salt buffer mixture of pure chemistry. Buffering due to carbonic acid-bicarbonate equilibria only takes place above pH 6.0 or 6.8. Since the final titration curves of the soil are only obtained after several days, this process is not considered as straight neutralization. Neutralization in the purely chemical sense results immediately even with incomplete dissociation of the reacting constituents. Moreover, the titration curves with acid and base are unlike but have the highest similarity with those of heterogeneous mixtures and not those of simple neutralization processes.

Maiwald gives six factors that affect the course of the titration curve as follows: (a) The base-combining capacity of the acidoid complex which is determined by the individual chemical character of the complex (pure clay and pure humus). (b) The degree of saturation of the colloid complex with bases. (c) Absolute content of the soil in reactive constituents (colloidal clay and humus). (d) The degree of dispersion of the reaction constituents and its change during titration. (The curve flattens as dispersion takes place, due to an increase in surface.) (e) The kind (Ca, Mg, K, Na) and relative amounts of exchangeable bases present and their influence on the degree of dispersion. (f) The nature of the titrating agent.

These factors are grouped into material, concentration, and secondary factors as represented by groups a and b, c and d, and e and f, respectively. Buffering is characterized by the equation

c, d (e) equiv. of a, b, acidoid + n equiv. (f) KOH = buffering (4)

This expression is explained as follows: A colloidal soil acidoid of base exchange capacity, a, and with degree of saturation with bases, b, is present in the soil in c grams per gram of soil. The soil has a relative degree of dispersion, d, as affected by secondary influences (e). It is titrated with n equivalents of KOH which cause a change in the degree of dispersion of the soil, d, according to the function, f. The summation of these factors produces a certain buffered equilibrium.

The concepts of Bradfield, Wiegner, Kappen, Behrens, and Maiwald are somewhat similar in that they attribute the buffer action in soils to reactions involving the soil exchange complex. The chief differences exist in the interpretation of the nature of these reactions.

Goy (7) assumes that the soil colloids contain a base-covered and a base-free zone, both of which are capable of taking up base. The base-covered zone is determined by titration with HCl. The base-free zone is titrated with NaOH. He finds that maximum buffer capacity occurs at the neutral point. The following quantitative relationships between acidity, absorption, and buffering are formulated: (a) There is a specific relationship between acidity, absorptive capacity, and buffering powers of soils so that a change in one of these factors quantitatively influences the others. (b) Each soil has a characteristic base-combining capacity that is generally composed of a base-free and a base-covered zone. (c) The ionic density (the ratio of the amount of base which is necessary for the neutralization of a determined acid part to that amount of base which is used for neutral adsorption) is specific for these quantitative relationships. (d) The buffer value for

the same soil is different at different pH values. It is specific for each soil. (e) All acidity, absorption, and buffering values can be determined from a titration curve.

This concept of Goy, although stressing some of the very fundamental points relative to soil buffer action, is extremely different in that it considers maximum buffering as taking place at the neutral point where most of the exchangeable H ions are neutralized.

Meyers and Gilligan (13) in some recent investigations advance the theory that soil buffer action is the result of a repression of ionization of the added acid by crystalloidal salts. The formation of these salts takes place according to the equation:

$$\begin{matrix} Na: \\ K\ : \\ Ca: \\ Mg: \end{matrix} \text{colloid} + HCl \rightleftharpoons \begin{matrix} Na: \\ K\ : \\ Ca: \\ Mg: \end{matrix} Cl + \text{H-colloid} \qquad (5)$$

This process takes place as follows: "When an acid is added to the soil it reacts with the salts of colloidal acids forming colloidal acids and crystalloidal salts. The resultant reaction of the system is only slightly altered in consequence of the weakness of the colloidal acids. When acid is added in excess of that required to react with the cations of the crystalloidal salts, the crystalloidal salts formed, having an ion in common with the added acid, tend to repress the ionization of the latter. The net result is a small change in the hydrogen-ion concentration of the soil dispersion." The buffer capacity is considered to be destroyed by electrodialysis of the bases from the colloid.

This explanation differs from those previously discussed in that it eliminates any direct effect of the exchange complex and the colloidal clay acids upon the buffering of the soil system.

Recent studies by Baver and Scarseth (2) have indicated that the buffer action in soils is primarily a function of the colloidal clay acids. The data, however, did not show conclusively that the nature of the colloidal acid is the predominant factor in the buffering properties. It is apparent, therefore, that further experimental investigations are necessary in order to clarify the apparent discrepancies between the various interpretations of soil buffer action.

SOIL CONSTITUENTS AFFECTING BUFFER ACTION

EXPERIMENTAL

The experiments in this investigation were designed to show the effect of the following factors on the buffering properties of soils: (a)

Amount of colloid; (b) the nature of the colloid; (c) the presence of organic matter; (d) the presence of free SiO_2, Al_2O_3, and Fe_2O_3; and (e) the presence of phosphates.

Ten grams of soil or 2 grams of colloid were electrodialyzed in a Bradfield three-compartment cell until free from exchangeable basic cations and acid anions. This process produced a pure soil or colloid which could be studied without any secondary anion effects other than that of the OH ion. The electrodialyzed soils or colloids were titrated potentiometrically by means of the hydrogen electrode, using N/10 NaOH. The base was added in increments of from 1 to 4 milliequivalents per 100 grams of soil or colloid. The soils or colloids were thoroughly shaken in a mechanical shaker for 2 hours after the addition of the base and allowed to stand 24 hours before the pH readings were made. Previous work has shown that equilibrium is not obtained immediately after the addition of a base (2). Increments of base were added to bring the pH value of the soils or colloids to approximately 9.0, which was always above the pH value at the point of supposed neutralization of the replaceable hydrogen. The point of neutralization was determined from the flex point in the curve as described by Bradfield (5). Soils containing different amounts of the same type of colloid and soils having the same quantity of colloids that were chemically different were chosen to study the effect of the amount and nature of colloidal material upon the buffer action.

In order to study the effect of organic matter, 10 grams of soil or 2 grams of colloid were oxidized at 60° C with a 6% solution of hydrogen peroxide. The oxidation process was continued until no evolution of gas took place upon further additions of the peroxide. The oxidized soil or colloid was washed with water and then electrodialyzed and treated as previously outlined. About 85% of the organic matter was oxidized by this treatment.

Soluble oxides of Al, Fe, and Si were removed by alternate extraction of the colloids with 2% Na_2CO_3 and N/10 HCl at 60° C. The colloids were washed with water before each addition of acid or base by removing the supernatant liquid with suction through a porous filter tube. Extraction was continued until there was no alumina in the supernatant liquid. The colloids were electrodialyzed and titrated potentiometrically with N/10 NaOH.

The effect of the presence of phosphates was determined by adding N/10 H_3PO_4 to 10 grams of electrodialyzed soil at rates equivalent to 3, 5, and 10 tons of 16% superphosphate per acre. Titration curves were made of these treated soils.

RESULTS

The results of these experiments are graphically shown in Figs. 1 to 5. The pH values after each addition of base are not given in tabular form because the titration curves show the effects of the studied factors much clearer.

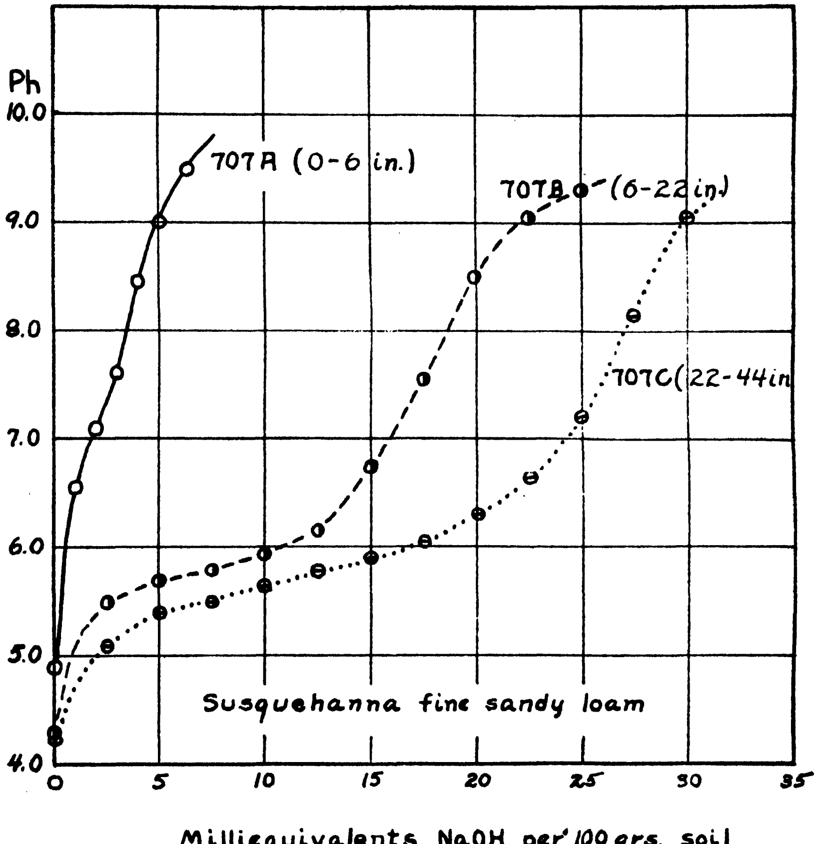


FIG. 1.—The effect of the amount and nature of the soil colloids upon buffer action.

The effect of the amount of colloid. It is a well-known fact that soils with high colloid contents are generally most strongly buffered. This is chiefly due to the higher absorptive capacity of the soil for bases as a result of the presence of the colloidal material. The effect of different amounts of the same type of colloids on buffer action is shown in Fig. 1, curves 707A and 707B. Previous work has shown that the nature of the acid in these two soils is practically the same (2). The SiO_2-sesquioxide ratios of the colloidal material are 2.27 and 2.11,

respectively, for 707A and 707B. The percentage of colloid, however, is extremely different, there being 6% in 707A and 57% in 707B. These curves are typical of the effect of the colloid content of soils upon their buffering properties. As the amount of colloid increases, the exchange capacity of the soil increases; consequently, there are more H ions to replace and neutralize. Much more base is required

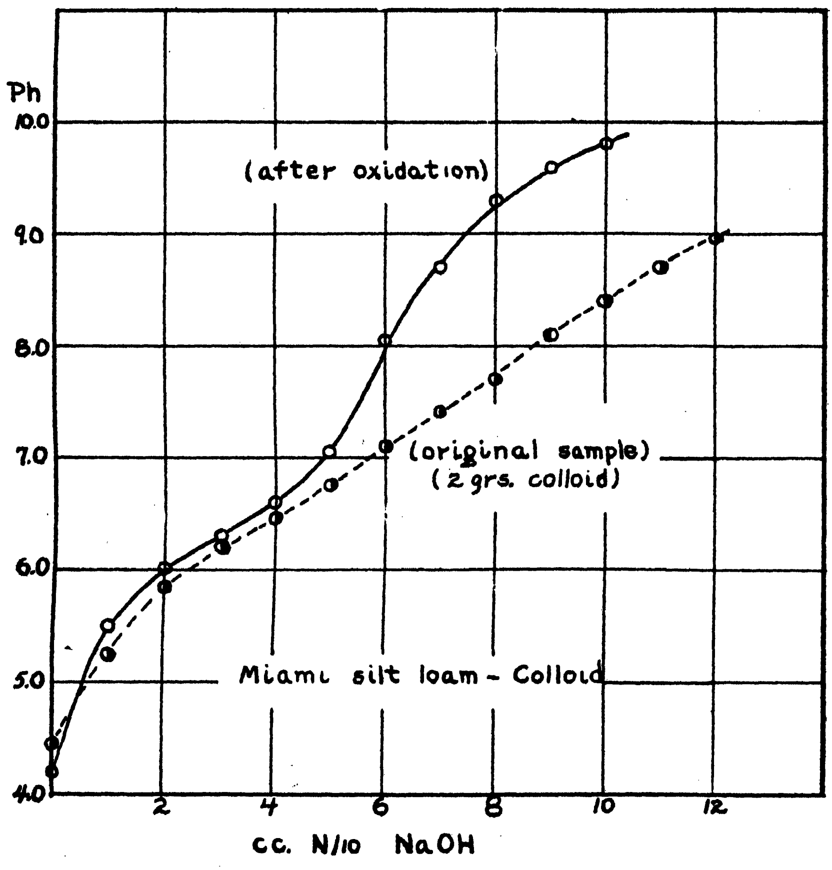


FIG. 2.—The effect of organic matter on the buffering of soil colloids.

to change 707B from pH 4.9 to 7.0 than to produce a corresponding change in the pH of 707A. This is simply because the former contains 19.0 milliequivalents of exchangeable hydrogen and the latter 3.5 milliequivalents.

The effect of the nature of the colloid. Curves 707B and 707C in Fig. 1 show the relationship between the buffering properties of soils and the nature of the colloid. These two soils contain approximately the same amount of colloid, there being 57% in 707B and 53% in

707C. The nature of the soil acids, however, are different (2). The SiO_2-sesquioxide ratio of 707B is 2.11, that of 707C is 3.25. As a result of differences in the type of the colloidal clay acids, 707C is the more highly buffered. Previous studies have shown that colloidal material with a wide SiO_2-sesquioxide ratio generally possesses a larger

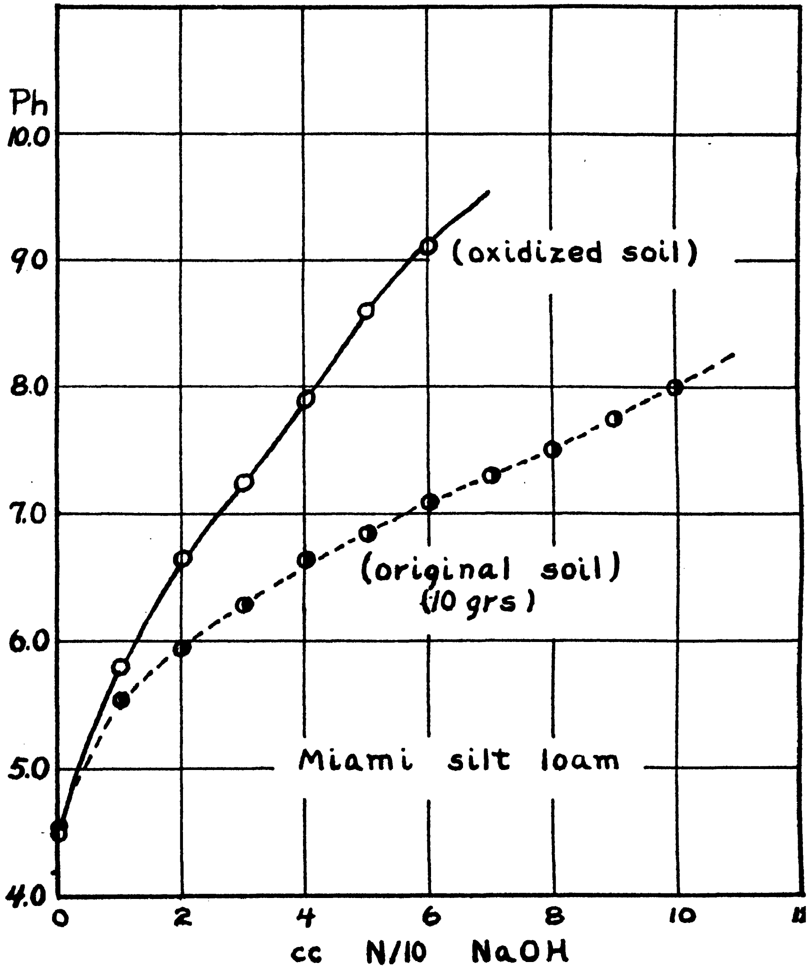


FIG. 3.—The effect of organic matter on the buffering of a soil.

buffer capacity than material with a narrower ratio (2). Similar observations have been reported by Pierre (16). These results clearly show that the nature of soil buffer action cannot be solely related to the amount of colloidal material present. The nature of the colloidal clay acids plays a significant rôle.

The effect of organic matter. Many statements have been made

that organic matter in soils is responsible for buffer action. Soils with relatively high amounts of organic matter have always exhibited considerable resistance to changes in their pH values. Buffering has been associated with the high absorptive capacity of the organic matter for bases. Odén (14) has shown that humic acids are present in soils which have the properties of weak acids and, therefore, could exert buffering properties due to dissociation phenomena.

The curves in Figs. 2 and 3 illustrate very clearly the buffering effects of organic matter. These curves confirm the observations of Wiegner and Gessner (17) that organic matter acts as a buffer more strongly in the alkaline region. The effect of organic matter on the buffering of the colloid from Miami silt loam is not manifested until an approximately neutral reaction is reached, pH 6.5 (Fig. 2). Organic matter appears to exert its influence on the buffering of the soil at pH 6.0 (Fig. 3). The colloidal material contained about 6% organic matter before oxidation and the soil about 3.5%. Between 80 and 85% of the original organic matter was oxidized by the H_2O_2 treatment.

The significant fact from these curves is that the nature of the mineral colloidal acid is the chief factor in the buffer action. Oxidation with hydrogen peroxide did not affect the nature of the soil acid. Fig. 2 clearly shows that the effect of the mineral colloidal acid is predominant up to the neutral point where most of the exchangeable hydrogen is neutralized. Above the neutral point the high absorptive capacity of the organic fraction and the increase in its degree of dispersion are responsible for the main buffering properties of the system. Although in soils containing large amounts of organic material the effect of the organic colloids may be predominant over the mineral colloids, it appears that the buffering of most soils below the neutral point is dependent upon the nature of the mineral colloidal acids.

The effect of "free oxides." The presence of free oxides of Al, Fe, and Si in sufficient quantities may exert some influence on the buffering of soils. Kappen and Behrens attribute part of the buffering at low pH values to the presence of free alumina. The results of this study, however, show that these constituents in ordinary soils have very little effect on buffer action (Figs. 4 and 5). Removal of 11% of the Al, Fe, and Si from 707A (Fig. 4) and 7.1% from 707C (Fig. 5) did not influence the nature of the inorganic colloidal acid. The total absorptive capacities of the colloids, however, were decreased slightly by this treatment, the SiO_2-sesquioxide ratio remaining unchanged. The buffering of the original colloid in 707A (Fig. 4) above pH 7.0 is due to the presence of organic matter. Treatment with Na_2CO_3

dissolved the organic colloids which were removed by subsequent washing. This confirms the data from the hydrogen peroxide treatments.

Although these colloids may not have contained sufficient quantities

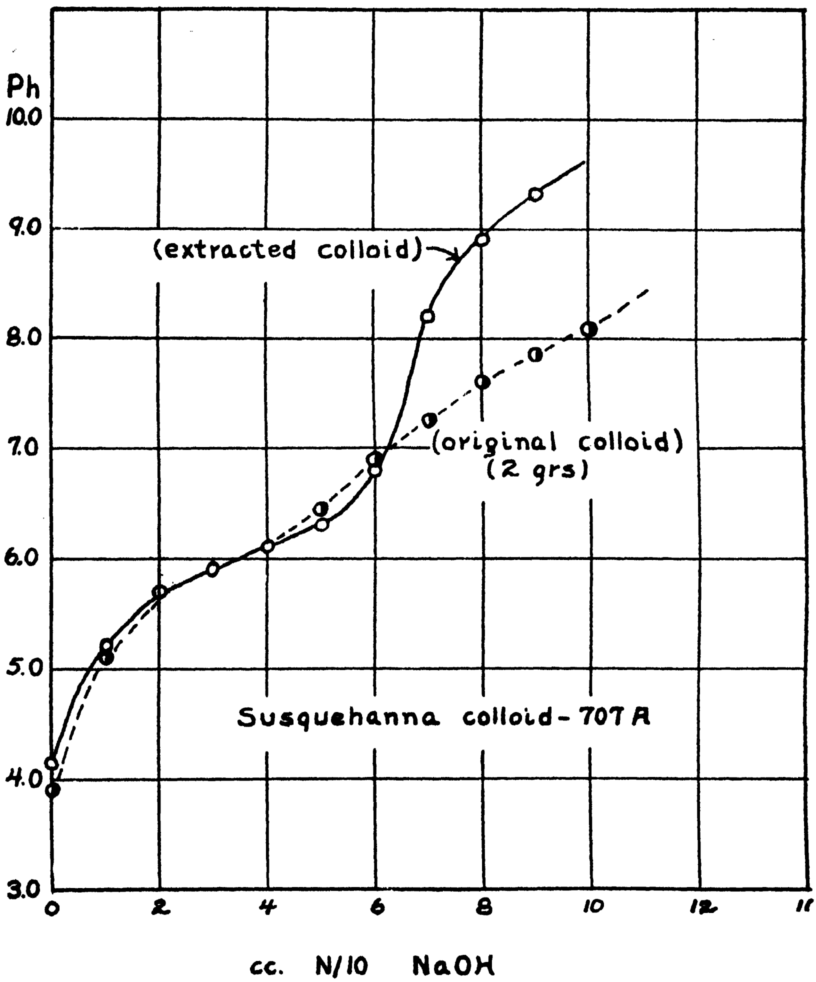


FIG. 4.—The effect of extraction with Na_2CO_3 and HCl on the buffering of soil colloids.

of "free oxides" to affect their buffering properties, it appears that the nature of the inorganic colloidal acids is primarily responsible for the buffer action. These colloidal acids are very stable as shown by their resistance to alternate extraction with 2% Na_2CO_3 and N/10 HCl as well as to oxidation with H_2O_2.

The effect of phosphates. Although some investigators have suggested that phosphates impart buffering properties to soils, results in this investigation have shown the opposite to be true. Applications of N/10 H_3PO_4 to electrodialyzed Cecil and Putnam clays, at the rate of 3, 5, and 10 tons superphosphate per acre, had no appreciable effect

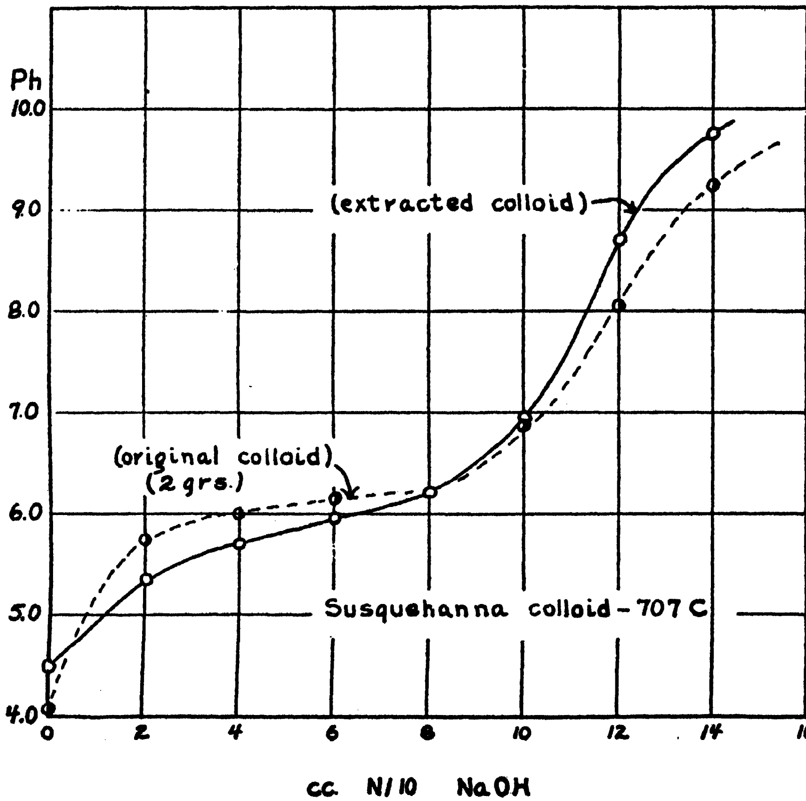


FIG. 5.—The effect of extraction with Na_2CO_3 and HCl on the buffering of soil colloids.

on the buffering of these soils. This should be expected if one compares the high buffering capacity of the colloidal clay acids with the amounts of phosphate added, and if one considers the PO_4 ions that are fixed by the soil. Since these amounts of phosphate (which are much larger than any practical applications) showed no effect upon soil buffer action, the titration curves of the soils after the addition of phosphate are not given in this paper. The curves would coincide to such an extent that they could not be reproduced very clearly in their publication.

DISCUSSION

An analysis of these results clearly shows that the nature of soil buffer action is solely a function of the amount and nature of the colloidal acids present, and primarily dependent upon the amount and nature of the mineral colloidal clay acids. Organic colloidal acids impart buffering properties to soils only in slightly acid, neutral, or alkaline reactions. This increase in buffer action due to the organic colloids is undoubtedly due to the nature of the organic acid and to an increase in surface as a result of more complete dispersion.

Buffer action is dependent, therefore, on equilibria between the weak colloidal clay acids and their salts. This phenomenon is somewhat similar to the buffering of weak acids and their salts in pure chemistry and may be expressed according to the equation

$$pH = y\left[pK + \log\frac{[\text{salt of colloidal clay acid}]}{[\text{colloidal clay acid}]}\right] \qquad (6)$$

where pK = negative logarithm of the apparent dissociation constant of the colloidal clay acid, and y = variable or variables which affect this equation, namely, degree of dissociation, hydrolysis, and solubility of the colloidal clay salts as related to the nature of the cation on the colloidal complex.

The degree of dissociation, hydrolysis, and solubility of the colloidal clay salts affect the course of the titration curves. Previous work by the writer (1) has shown that the titration curves exhibit more buffer action when the hydroxides of the divalent bases are used in the titration. The changes in pH per increment of base added was greatest according to the cation series Li $>$ Na $>$ K $>$ Mg $>$ Ca. These differences are due to the higher degree of dissociation and hydrolysis of the Li-, Na-, and K-clays as compared with the Mg- and Ca-clays. The differences between the curves obtained with the hydroxides of the monovalent cations are due to the hydration of the cations. Since the Li ion is more highly hydrated than the Na ion and the Na ion more highly hydrated than the K, the hydrolysis of the colloidal clay salts will be greatest according to the series Li $>$ Na $>$ K.

Recent work by Jenny (9) has shown that hydrolysis of clays saturated at different degrees with basic cations takes place in acid reactions. His results throw a new light on the behavior of colloidal clay systems and explain several discrepancies in previous work by the author on the effect of different cations on the titration curves of colloidal clays. These differences were originally attributed solely to various degrees of dissociation of the colloidal clay salts. The application of equation

6, therefore, to a quantitative expression of the buffering of a soil is limited to the knowledge of the extent of hydrolysis and dissociation of the clay salts.

It is evident, therefore, that each soil has a specific buffering capacity which is associated with (a) the amount and nature of the colloidal material present and (b) the amount and nature of the exchangeable cation on the exchange complex. The extent of buffering will be different at the various pH values with a minimum at the point of saturation of the colloidal material for bases and a maximum at the point equivalent to the apparent pK value of the colloidal acid.

This concept harmonizes the views of Bradfield, Behrens, Kappen, Maiwald, and Wiegner. It clarifies their differences and emphasizes their similarities. It does not thoroughly coincide, however, with the concepts of Goy (7) and of Meyers and Gilligan (13).

Although the relationships 1, 4, and 5 suggested by Goy are in harmony with those set forth in this paper, his concept of the nature of buffer action is entirely different. His consideration that maximum buffer action occurs at the neutral point is at variance not only with experimental facts as obtained from the titration curves, but also with the generally accepted views of the nature of soil acidity.

The conclusions of Meyers and Gilligan appear to be somewhat unwarranted from an analysis of their technic and data. The fact that electrodialysis destroyed the buffering properties of soils can readily be understood when one considers that this process lowered the pH value of the colloid to that of the pure colloidal clay acid. Subsequent treatment with HCl would give results similar to a mixture of HCl and acetic acid. The H ions from the HCl would immediately cause a repression of the ionization of the weak colloidal clay acids and the measured H-ion concentration would soon be approximately that of the HCl.

The repression of ionization of any acid added to the soil by the crystalloidal salts which are formed with the cations of the soil acid may take place to a limited extent in a soil-acid suspension. This process, however, could not be expected to obtain in the soil under natural conditions because of the leaching away of the crystalloidal salts. There is the additional fact that the pH values obtained with the HCl treatment are much lower than those occurring in a natural soil. This concept, like that of Goy, does not take into consideration the effect of the nature of the colloidal clay acids. It does not seem plausible, therefore, that it is the logical explanation of the mechanism of soil buffer action.

The results of the present study in addition to the investigations of Bradfield, Behrens, Kappen, Maiwald, and Wiegner strongly indicate that soil buffer action is associated with equilibria involving the colloidal mineral and organic acids and their salts. The nature of these acids must be taken into consideration as well as their respective amounts in the soil.

EVALUATION OF THE BUFFER CAPACITY OF SOILS

Several methods have been proposed for quantitatively expressing the buffer capacity of different soils. Charlton (6) expresses the total buffer capacity by two equations:

$$\text{Buffer capacity towards acid} = \frac{\text{cc N acid/100 gr. soil to give pH A}}{\text{X-A}} \tag{7}$$

$$\text{Buffer capacity towards base} = \frac{\text{cc N alkali/100 gr. soil to give pH B}}{\text{B-X}} \tag{8}$$

where A = any desired pH with acid, B = any desired pH with base, and X = pH value of the soil before acid or base additions.

It is very evident that these expressions do not readily give the relative buffer capacities at different pH values, even though they are a fair criterion of the total buffer capacity of different soils.

Jensen (10) uses the "buffer surface" for characterizing the buffering capacity. He measures the surface between the titration curve of the soil and that of pure quartz sand and calls the area the "buffer surface." Since quartz sand has no buffering properties, this area is considered an expression of the total buffer capacity of the soil. The chief disadvantages of the method are that the buffer capacity at different pH values is not given and that the measurement of the surface is somewhat inconvenient.

Odén (15) uses two expressions for evaluating soil buffer action, namely, coefficient of buffer action (δ) and the buffering effect (β). The coefficient of buffer action for a soil saturated to a certain degree with bases and, consequently, characterized by a definite pH value, is defined as the fraction of OH ions which, when an infinitely small addition of base is made to a soil suspension, is taken up and not left free in solution. The buffering effect (β) is defined as the integral of δ from the base addition zero to a given addition (b) of the base. These variables depend upon the degree of base saturation of the other soil constituents.

Behrens (3) expresses the buffer capacity of soils by the buffer

quotient and the buffer integral. The former is the increment of acid or base divided by the change in pH, that is, $\Delta A/\Delta pH$ or $\Delta B/\Delta pH$. It signifies a resistance to change in reaction and is a function of the pH number. The buffer integral is the amount of acid or base required to change the reaction a certain pH. It is independent of the acidity of the soil. Behrens plots the buffer quotient as the ordinate against pH

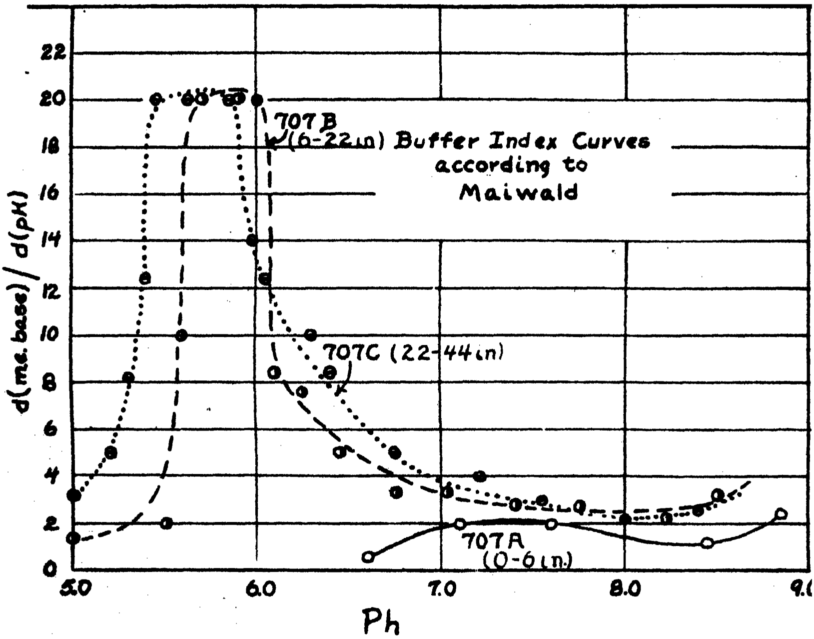


FIG. 6.—The buffer index curves of three different soils.

as the abscissa and obtains a curve which shows the buffer action at various pH values.

Maiwald (12) uses the buffer index, $\pi = \dfrac{\Delta A}{\Delta pH}$, to characterize the buffering of soils. It is the same as the buffer quotient of Behrens. He plots the buffer index against pH and obtains the same curve as Behrens which gives the relationship of buffer capacity to pH.

The buffer index curves of soils 707A, 707B, and 707C are shown in Fig. 6. The maximum buffering of 707B and 707C is exactly the same but occurs at different pH values. The maximum value for the former is reached at pH 5.70 and that of the latter at pH 5.40. This is due to differences in the nature of the soil acid, the acid in 707C being stronger than that in 707B. The buffer index curve of 707A

is not very high, indicating about the same amount of buffering at the different pH values with a maximum at about pH 7.0.

These curves show very clearly the amount of buffering at the various pH values. They do not give in their present form, however, the total buffer capacity of the soil. This value can readily be obtained from a summation of all of the π values according to the equation

$$\text{total buffer capacity} = \Sigma\, \pi \Big]_{\text{pH} = \text{original soil}}^{\text{pH} = \text{no exchangeable hydrogen present}} \tag{9}$$

This expression takes into consideration the effect of the amount and nature of the colloidal clay acids in the soil as well as the degree of saturation of the colloidal material with bases. Since the choice of the pH values between which the buffer capacity is calculated is more or less arbitrary between different investigators, it seems logical to choose the pH value of the original soil and that pH at which no exchangeable H ions are present. The latter pH value will vary with the soil and the nature of the base which is being used in its titration. The curves shown in this investigation indicate that this value with NaOH as the titrating base is about pH 8.5. Bradfield (5) found the same value for NaOH; that for $Ca(OH)_2$ or $Ba(OH)_2$ was observed to be pH 7.0.

The total buffer capacities of soils 707A, 707B, and 707C, calculated from equations 8 and 9, are given in Table 1. The data were obtained from the ratio $\Delta B/\Delta pH$, where ΔB in each case was one milliequivalent per 100 grams of soil. The pH at the saturation point of the soil for bases was 8.45, 8.50, and 8.40 for 707A, 707B, and 707C, respectively; the original pH values being 4.9, 4.3, and 4.25, respectively. These data were used in the calculations with both equations.

TABLE 1.—*The total buffer capacity of soils by two different methods.*

Method	Total buffer capacity		
	707A	707B	707C
Charlton equation 8	1.12	6.25	6.75
$\Sigma\pi$ equation 9	5.81	219.68	332.54

The results in Table 1 show that the Charlton equation gives much lower values for the total buffer capacity than equation 9. This is because it does not consider the strong buffer action exhibited at the flat portion of the titration curves. The summation of the π values emphasizes the buffering at each pH and should be a better index of

the total buffer capacity. An analysis of the curves in Fig. 1 shows that 707B is much more strongly buffered than 707A. The calculations from equation 9 confirm these observations; those from equation 8, however, do not show the exact magnitude of the differences between these two soils.

It is evident, therefore, that the methods of Behrens and Maiwald give a clear picture of the buffer capacity of soils. The extent of buffering at each pH number is clearly shown by plotting the π values of any soil, per milliequivalent of base added, against pH. The summation of the π values from the original pH of the soil to that corresponding to the point of base saturation of the soil gives a fairly accurate estimate of the total buffer capacity. The data obtained in this manner are based upon the principles of soil buffer action as discussed in the first part of this paper.

SUMMARY

The following conclusions have been obtained from an analysis and discussion of the different factors affecting the nature of soil buffer action:

1. The buffering of soils containing different amounts of the same type of colloid increases with the colloid content.

2. Soils containing the same amount of colloid may have different buffering properties due to variations in the nature of the colloid.

3. Buffering due to organic matter takes place only in slightly acid, neutral, or alkaline reactions.

4. Extraction of soluble Al_2O_3, Fe_2O_3, and SiO_2 did not materially affect the buffering of soil colloids.

5. Applications of phosphate equivalent to 3, 5, and 10 tons of superphosphate (16% P_2O_5) per acre did not impart buffering properties to the soil.

6. The nature of soil buffer action is considered solely a function of the nature of the colloidal acids in the soil and primarily dependent upon the inorganic colloidal clay acids. Organic colloidal acids are responsible for buffer action above the neutral point.

7. Buffering is due to equilibria between these colloidal acids and their salts as affected by hydrolysis, dissociation, and solubility phenomena.

8. The total buffer capacity of soils is determined by the equation:

$$\text{Total buffer capacity} = \Sigma\frac{\Delta B}{\Delta pH} = \Sigma\,\pi \Big]_{\text{pH = original soil}}^{\text{pH = no exchangeable hydrogen present}}$$

This equation gives the buffering at various pH values as well as the total buffer capacity.

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SOME NEGLECTED SOIL FACTORS IN PLANT GROWTH[1]

A. H. MEYER[2]

The difficulty of growing normal plants in synthetic media is one of common experience. The reason is self-evident, for all the factors that influence plant growth are not well understood. In the matter of nutrition alone there is increasing evidence that more than 10 of the 80-odd chemical elements known are essential and indispensable to the life and growth of green plants. Some elements have apparently been overlooked owing to the fact that they are required in such small amounts, that either they have been supplied accidentally as impurities in the nutrient salts, or else the growth of the plant was continued for such a short period that the needs were supplied by small amounts stored in the seed.

Aside from the additional elements which may be essential for plant growth, there are factors connected with possible toxic conditions which may be important. Certain kinds of finely divided or colloidal material, such as kaolin, silica, and ferric oxide, which are found in soils may, when added to culture media, combine chemically or physically with toxic material produced in the culture media or excreted by plant roots, thus inhibiting the action of the toxins and greatly favoring root development and plant growth. That there may be factors of this kind is indicated by observations to the effect that plants usually grow better in a good soil than in the best artificial medium that may be prepared.

It was the purpose of this investigation to study some of the more or less neglected soil factors in plant growth which have just been mentioned.

REVIEW OF LITERATURE

Of the additional elements sometimes said to be essential, manganese has been given the most consideration. It is invariably present in soils and also in a large variety of plants and animals. In the analyses of 23 Italian soils reported by Contino (6),[3] the amounts of manganese oxide range from a trace to as high as 0.48%,

[1]Abstract of a thesis submitted at the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication February 28, 1931.

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[3]Reference by number is to "Literature Cited," p. 624.

the average being 0.17%. In Kentucky soils, according to Shedd (19), the percentage of manganese ranges from 0.05 to 0.331% in the surface soil and from 0.002 to 0.264% in the subsoil. He found that a high percentage of manganese is associated with rich soils, that the cultivated soils contain less manganese than the virgin soils, and that under cultivation manganese is usually lost more rapidly than phosphorus.

Jardin and Astruc (10) examined about 65 species of plants and found manganese in all of them. Their work also indicated a wide distribution of the element in the animal kingdom.

McHargue (14) found the largest amounts of manganese in those parts of the seed coats that immediately surround the cotyledons. He found, too, that manganese is relatively high in those parts which secrete large amounts of oxidizing enzymes. He indicates that manganese may serve as a catalyst to the enzymes.

Bertrand (1, 2) was probably the first worker to assign a definite rôle to manganese in plant nutrition. In pot experiments manganese increased the yield from 10 to 20%, while in the field the increase ranged from 20% with peas to 30% with alfalfa. He concluded that manganese is apparently not to be replaced by another element, not even iron, and that just because it occurs in small amounts is no reason for regarding it as a secondary element in plant nutrition.

Brenchley (4, 5), from work with pot cultures, concluded that manganese may be an essential element for plant nutrition, and noticed that it is toxic only in large amounts. Minute traces of this element in the form of a salt were found to have a very beneficial effect on both roots and shoots.

In 1916, Skinner and Reed (20) reported the results of a 6-year test in which 50 pounds of manganous sulfate per acre were applied on an acid and a neutral soil. On the neutral soil they received increased yields of wheat, rye, corn, timothy, beans, and cowpeas; but not potatoes. There was no apparent benefit on the acid soil. They concluded that on acid soil, manganese decreased the oxidation power, while on neutral soil it increased it. ✓

Hiltner and Korff, in 1925, concluded that manganese is only beneficial to plants in that it accelerates oxidation in the soil. Two years later McLean and Gilbert (17) showed that manganese is a cure for chlorotic spinach.

McHargue (15) argues that the statement, "the 10 essential elements are the only ones that have important functions in the growth of plants" is no longer tenable. He states that small amounts of manganese, copper, zinc, boron, barium, strontium, iodine, and

arsenic are normal constituents of plants grown under natural conditions on the fertile soils of Kentucky. Manganese, though less abundant, is as widely distributed as iron. Just lately McHargue and Shedd (16) have published data giving further support to these ideas.

Maze (13) found that it is impossible to grow plants in a culture solution without the addition of small amounts of several of the elements rare in the ash of plants. Sommer and Lipman (21), obtained evidence that silicon, aluminum, boron, zinc, and chlorine are essential.

From a study of the literature it appears that there is a growing opinion that other elements than the so-called 10 essential elements are necessary for the normal growth of plants. It is natural that investigators should first have centered their thoughts on the elements occurring in the largest amounts in plants. The apparently lesser important elements are required in such small amounts that they were undoubtedly often furnished in sufficient quantities as impurities in the nutrient salts and thus their presence or need were overlooked. Even the necessity of iron was overlooked until Knop's investigation, a little over a half century ago. With the development of new and more accurate methods of chemical analyses and with greater refinement in methods of research, it seems entirely probable that some of the elements now called unessential may prove to be essential and very important in the metabolism of plants.

Another factor involved in plant growth is that of toxins. Nageli (18) discovered as early as 1893 that by adding crushed graphite, shredded filter paper, paraffin, shavings, or other insoluble substances in a finely divided state to the culture medium the toxic effects of copper were entirely inhibited.

Dandeno (7) found that the finer the sand is in the culture medium the more pronounced is the reduction of the toxic effect of copper sulfate. Similar results were obtained by Jensen (11) with sulfuric acid.

In 1905, True and Oglevee (22) observed that the toxicity of solutions of silver nitrate and copper sulfate were materially reduced by the addition of such insoluble substances as quartz sand, powdered glass, shredded filter paper, and starch grains to the culture. Breazeale (3), on the other hand, in testing the toxicity of sulfuric acid to maize seedlings, was unable to reduce this toxicity by the introduction of quartz flour, filter paper, or paraffine to the solution. However, with copper sulfate the medium was materially ameliorated by the addition of carbon black.

Jensen (11) found that quartz flour reduces the toxicity in most cases, but not when due to phenol and alcohol which, like resorcinal, are very weak poisons to plants. His results are fully in agreement with those of True and Oglevee (22).

Livingston's (12) data reveal that all poor soils studied by him, as well as the aqueous extracts of these soils, were appreciably improved by the addition of calcium carbonate. Similar results were obtained by Breazeale (3).

The data of Breazeale bring out the point that the effects of calcium carbonate and ferric hydrate (chemical agents) are much more pronounced than are those of carbon black and quartz flour (physical adsorptive agents.)

Funchess (8) reports that a normal soil can apparently dispose of enormous quantities of organic compounds through physical, chemical, and biochemical action.

In 1916, Truog and Sykora (23) made a study of soil constituents which inhibit the action of plant toxins. The insoluble materials used were quartz sand, quartz flour, kaolin, and Superior clay. Their data indicate that in the inhibition of toxicity, chemical reaction is a more important factor than physical phenomena, such as adsorption.

EXPERIMENTAL

INFLUENCE OF KAOLIN AND OTHER SOIL MATERIAL ON PLANT GROWTH

Kaolin is widely distributed and is found in considerable amounts in most soils. It seemed desirable, therefore, to study its possible influence on plant growth. In some preliminary experiments the effect of adding 1% of kaolin to quartz sand cultures of oats which otherwise received a complete nutrient solution was studied. The results secured were as follows:

Treatment	Weight of seeds in grams	Weight of dry tops in grams	Weight of dry roots in grams
Control	5.048	10.93	4.23
100 grams kaolin	8.35	12.20	5.59

These results indicate that some factors affecting plant growth, but usually neglected, are connected with the addition of kaolin. In order to determine what these factors might be, more extensive experiments were planned the following year. As regards the factors involved there appeared to be at least three possibilities, *viz.*, (a) that kaolin contains as impurities small amounts of additional elements necessary for plant growth; (b) that kaolin in some way

benefits plant growth, possibly by combining with toxic material of a basic nature; and (c) that the colloidal property affects plant growth through physical means.

A very high grade of natural quartz sand, analyzing over 99% silica, was used for the synthetic sand cultures. The kaolin used was fairly pure material from Dry Branch, Georgia. Only the portion passing a 100-mesh sieve was used. In order to study the influence of other non-nutrient soil material than kaolin on plant growth, some Miami silt loam which had been cropped until low in fertility was added to some of the cultures. It had a reaction of pH 6.5. The soil was passed through a 100-mesh sieve before being mixed with the quartz sand.

High grade tested chemicals were used to make a basal nutrient solution according to the following formula:

Salts used	Grams per liter of solution
$NaNO_3$	0.625
$Na_2HPO_4.12H_2O$	0.462
KCl	0.382
$Ca(NO_3)_2.4H_2O$	0.240
$MgSO_4.7H_2O$	0.075
$FeCl_3.6H_2O$	0.014

Earthenware glazed pots of 2-gallon capacity were filled with 11 kilograms of quartz sand. One liter of the nutrient solution was added to each jar. The moisture content was brought up to 13% and maintained there until the crop was harvested. The reaction of the nutrient solution was pH 7.1.

Alfalfa, buckwheat, oats, and corn were grown with five different treatments as follows:

1. Control
2. 100 grams kaolin
3. 200 grams kaolin
4. 400 grams kaolin
5. 400 grams of Miami silt loam

The control quartz culture received only the basal nutrient solution. In the case of oats, an additional pot was added containing 10 kilograms of quartz sand and 1 kilogram of kaolin. The kaolin and sand were mixed thoroughly in the dry condition.

After the plants were up, they were thinned to 10 of buckwheat, 9 of oats, 12 of alfalfa, and 3 of corn. The alfalfa was inoculated. The pot cultures were placed in the greenhouse and kept at an approximately constant moisture content by the addition of distilled water from time to time.

The crops were all sown February 23 and excepting oats were harvested April 30. Oats were harvested May 13.

Alfalfa was the first crop to show differences in growth. After the elapse of 10 days the plants in the sand cultures with kaolin were decidedly better, having larger leaves which were also darker green in color. The plants grown in quartz sand alone were spindling and yellow in color. The addition of 400 grams of Miami silt loam did not act as favorably as 100 grams of kaolin. Phosphorus starvation was suspected and an application of phosphorus to one of the duplicates produced a very quick response, thus substantiating the surmise that phosphorus was the limiting factor. Apparently the soluble phosphate was tied up to some extent by the soil.

The alfalfa roots in the quartz sand culture had very few nodules, whereas those in the quartz sand with kaolin and in the quartz sand with Miami silt loam had a large number of nodules, and, in addition, the root development was much better.

The weights of air-dry tissue produced, given in Table 1, show the beneficial effect of Kaolin and Miami silt loam on plant growth in quartz sand cultures.

TABLE 1.—*Effects on the growth of alfalfa of the addition of kaolin and Miami silt loam to quartz sand cultures.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	2.00	1.65
2	100 grams kaolin	4.50	5.05
3	200 grams kaolin	4.60	5.03
4	400 grams kaolin	5.01	4.50
5	400 grams Miami silt loam	4.70	3.85

It is evident that the kaolin had a very beneficial effect on root development. This effect is not nearly as evident with Miami silt loam.

There were noticeable differences in the growth of buckwheat with the various treatments which showed up about two weeks after planting. The plants in the quartz sand culture were spindling and the leaves pale green in color, while the plants in the cultures with quartz sand and kaolin and quartz sand and Miami silt loam were thicker in the stalk and darker green in color. At all times the best growth appeared in the quartz sand culture with 400 grams of Miami silt loam. This was contrary to the observations with alfalfa. This might be explained by the fact that buckwheat can utilize difficultly soluble phosphates more readily than alfalfa. Just before

inflorescence, the plants in the quartz sand culture were drooping, the stalks spindling, and the leaves small and pale green. On the other hand, those grown in the quartz sand culture with kaolin were rigid, the stalks thick, and the leaves larger and darker green.

FIG. 1.—The growth of buckwheat in quartz sand culture with the addition of kaolin and Miami silt loam. 1. Control. 2. 100 grams unwashed kaolin. 3. 200 grams unwashed kaolin. 4. 400 grams unwashed kaolin. 5. 400 grams Miami silt loam.

The comparative growth of buckwheat with the various treatments is shown in Fig. 1. The weights of seeds, tops, and roots are given in Table 2.

TABLE 2.—*Effect on the growth of buckwheat of the addition of kaolin and Miami silt loam to quartz sand cultures.*

Pot No.	Treatment	Weight of seeds in grams, ave. of two	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	1.10	3.75	0.24
2	100 grams kaolin	2.51	5.15	0.70
3	200 grams kaolin	3.53	4.20	0.75
4	400 grams kaolin	3.23	5.95	0.70
5	500 grams Miami silt loam	4.24	4.10	0.45

The data in Table 2 are in agreement with the observations made of the general appearance of the plants, with the exception of the plants grown with Miami silt loam. In this case, the weight of the tops, contrary to expectation, was not the heaviest. As in the

case of alfalfa, the root development was the largest in the quartz sand with kaolin. There was no significant difference in plant growth with varying amounts of kaolin.

When it comes to the total weight of seed produced, the general appearance of the plants was a true criterion. The weight increased sharply from set 1 to set 2 and gradually from set 2 to set 5. Only in set 4 did the weight of seed exceed that of the tops.

In the series of experiments with oats, the quartz sand cultures with kaolin and with Miami silt loam gave a superior growth to that of the quartz sand culture alone. At the end of two weeks' growth, the oats in the quartz sand were spindling and the leaves pale yellow, whereas, with the treatments of kaolin they were stalky and dark green in color. In the kaolin series, the oats with 400 grams of kaolin were the tallest. The plants grown in quartz sand cultures with Miami silt loam were shorter and had thinner stalks and paler leaves than those grown in quartz sand with kaolin.

At harvesting time the plants grown in quartz sand with 1,000 grams of kaolin were the tallest and had the thickest stalks and darkest colored leaves of any in spite of the somewhat retarded growth at the time the photograph was taken. The dark green color was especially noticeable in contrast to the plants in the quartz sand cultures. The weights of tops and roots are given in Table 3.

TABLE 3.—*Effect on the growth of oats of the addition of kaolin and Miami silt loam to quartz sand cultures.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	6.00	1.51
2	100 grams kaolin	10.90	4.95
3	200 grams kaolin	13.10	6.25
4	400 grams kaolin	11.60	5.95
5	400 grams Miami silt loam	11.00	4.50
6	1,000 grams kaolin	17.10	6.40

As indicated in Table 3, the kaolin had a very beneficial effect on the root development of the oats, as it did in the case of alfalfa and buckwheat. The heaviest root growth was obtained with 200 or more grams. The highest weight of tops was secured where 1,000 grams were used, though very beneficial results were obtained from lesser amounts. The plants grown in quartz sand cultures with 400 grams of Miami silt loam were not nearly as good as those grown in quartz sand with the different amounts of kaolin, but nevertheless, appreciably better than those grown in the cultures with quartz sand alone.

At the end of the third week, corn growing on quartz sand with 200 grams of kaolin was decidedly better than that growing on the quartz sand culture. The corn plants in the quartz sand cultures had a characteristic pale green color and the leaves were narrow. In the case where kaolin was added, the stalks were thicker, and the leaves decidedly darker in color. The corn in the quartz sand culture with 400 grams of Miami silt loam was not as good as in the case where kaolin was used. The leaves had reddish streaks indicating the presence of anthocyan, apparently showing a shortage of phosphorus. The weights of tops and roots are given in Table 4.

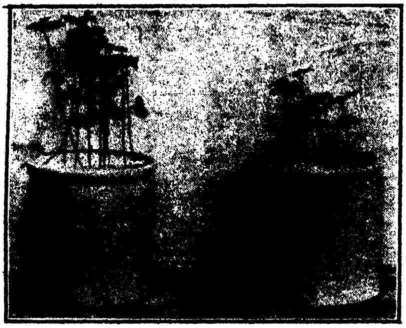

FIG. 2.—The effect on the growth of buckwheat of the addition of washed kaolin to quartz sand culture. 1. 200 grams washed kaolin. 2. Control.

The data in the table indicate that the quartz sand culture with 400 grams of kaolin produced the highest weight of tops, as well as of roots. The yield from the quartz sand with Miami silt loam was considerably lower. However, it is about the same as from the quartz sand with 100 and 200 grams of kaolin. The quartz sand alone gave by far the lowest yield.

TABLE 4.—*Effect on the growth of corn of the addition of kaolin and Miami silt loam to quartz sand culture.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	12.50	5.20
2	100 grams kaolin	17.00	6.31
3	200 grams kaolin	17.10	6.80
4	400 grams kaolin	21.50	8.30
5	400 grams Miami silt loam	17.00	5.75

It was thought that the beneficial effect of kaolin to plant growth might be due to certain elements found as impurities in kaolin, usually not considered essential. In order to remove the impurities from the kaolin, it was subjected to a treatment of 0.18 N HCl for 24 hours, washed until it gave no further test for chlorides, and then dried and put through a 100-mesh sieve.

Buckwheat was chosen for this next experiment because of its quick growth. The experiment was conducted in the same way as the previous ones. Two pots were provided with quartz sand and two with quartz sand plus 200 grams of washed kaolin.

The same general results were obtained with the washed kaolin as with the unwashed as is shown in Fig. 2. The weights of oven-dried material are given in Table 5.

TABLE 5.—*Effect on the growth of buckwheat of the addition of washed kaolin to quartz sand cultures.*

Pot No.	Treatment	Weight of seeds in grams, ave. of two	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	2.05	2.20	0.32
2	200 grams kaolin	2.60	2.80	0.60

Since the last traces of manganese could not be removed from kaolin by the acid washing, the following experiment was conducted in order to test the beneficial effect of certain elements usually considered unessential. The basal nutrient solution was shaken in one case with 20 grams of kaolin and in another with 20 grams of Miami silt loam for 12 hours. These solutions were filtered before using. In another set of pots, the distilled water used for watering was treated, in one case, with 400 grams of Miami silt loam and, in another, with 400 grams of kaolin. In this experiment there were seven different treatments, including the control, as indicated in Table 6, which also gives the yields.

TABLE 6.—*Effect of kaolin and Miami silt loam on the growth of buckwheat in quartz sand culture.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	4.15	0.35
2	Basal nutrient solution treated with 20 grams soil	3.45	0.23
3	Basal nutrient solution treated with 20 grams kaolin	5.95	0.30
4	200 grams kaolin	8.27	0.75
5	500 grams of Miami silt loam	9.68	0.60
6	Distilled water for watering, treated with soil	3.85	0.23
7	Distilled water for watering, treated with kaolin	6.16	0.55

As in the previous experiment with buckwheat, the quartz sand with kaolin and the quartz sand with soil produced the best growth. The plants of the control were drooping, spindling, and yellow in

appearance. However, the plants in the quartz sand culture, the basal solution of which had been treated with soil, were even poorer than the control. The soil treatment decreased the supply of phosphorus to such an extent that it was the limiting factor. When the nutrient solution was treated with kaolin, some improvement was noticed over the control. The plants, however, were subnormal, the leaves pale yellow, and the plants did not possess the rigidity of the normal plants. When the basal solution was made up with dis-

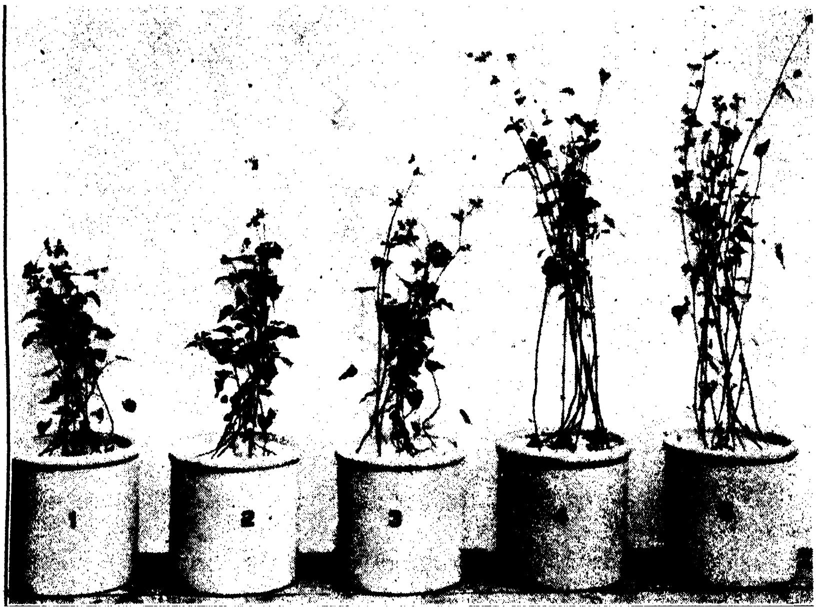

FIG. 3.—Various effects of kaolin and Miami silt loam on the growth of buckwheat. 1. Control. 2. Basal nutrient solution treated with 20 grams soil. 3. Basal nutrient solution treated with 20 grams kaolin. 4. 400 grams Miami silt loam with basal nutrient solution. 5. 200 grams kaolin with basal nutrient solution.

tilled water treated with soil, the growth of buckwheat was the poorest, though where kaolin was used, the growth was somewhat better than the control. Fig. 3 gives the comparative growths.

INFLUENCE OF OTHER THAN 10 USUAL NUTRIENT ELEMENTS ON PLANT GROWTH

Another experiment with buckwheat was conducted to study the effects of the addition of a number of the elements found in small amounts or traces in the ash of plants. These different elements

were added along with the usual basal nutrient solution to quartz sand cultures in forms and amounts as follows:

Boron as H_3BO_3, giving 0.5 mgm B per culture
Zinc as $ZnSO_4$, giving 0.5 mgm Zn per culture
Aluminum as $AlCl_3$, giving 0.5 mgm Al per culture
Manganese as $MnSO_4$, giving 1.5 mgm Mn per culture
Copper as $CuSO_4.5H_2O$, giving 0.125 mgm Cu per culture
Iodine as KI, giving 0.25 mgm I per culture
Fluorine as NH_4Fl, giving 0.25 mgm Fl per culture

FIG. 4.—Effect of additional elements other than the 10 essential elements on the growth of buckwheat. 1. Control. 2. Boron. 3. Zinc. 4. Boron and zinc. 5. Boron, zinc, and aluminum. 6. Boron, zinc, aluminum, and manganese. 7. Boron, zinc, aluminum, manganese, and copper. 8. Boron, zinc, aluminum, manganese, copper, and iodine. 9. Boron, zinc, aluminum, manganese, copper, iodine, and fluorine.

The various treatments and results are given in Table 7. Lack of time and facilities did not allow the experiment to be carried out in greater detail so that all of the elements could be tested singly and in various combinations.

TABLE 7.—*Growth of buckwheat produced in quartz sand cultures when additional elements are added to the basal nutrient solution.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	2.64	0.29
2	B	3.05	0.36
3	Zn	2.98	0.35
4	B and Zn	3.65	0.39
5	B, Zn, and Al	3.75	0.42
6	B, Zn, Al, and Mn	5.40	0.55
7	B, Zn, Al, Mn, and Cu	4.00	0.40
8	B, Zn, Al, Mn, Cu, and I	6.20	0.58
9	B, Zn, Al, Mn, Cu, I, and Fl	4.07	0.40

In about 10 days, the plants in pots 5, 6, 7, 8, and 9 were ahead of those in the control. They were of a darker green color, thicker in stalk, and more rigid than the plants in the control. Plants in pots Nos. 2 and 3 were about the same as the plants in the control.

At time of harvesting, as indicated in Fig. 4, the plants in all the treated pots were better than those in the control. The plants with the addition of boron alone, though taller, were spindling and not much better than those in the control. With the addition of zinc, the plants were not quite as tall as with the addition of boron, but were thicker in stalk. The boron and zinc combination was decidedly better than either alone. Aluminum was the first element in the series to produce marked beneficial results. The stalks of the buckwheat were thicker, the leaves larger, and darker green in color. With the addition of manganese, still further improvement in growth was noted. The plants were normal and characterized by a stiff, rigid stem structure. The addition of copper showed a detrimental effect. The plants were spindling and not normal in color. The application of iodine in addition to the others produced the most luxuriant growth. Fluorine offset the benefits of iodine and was apparently detrimental.

Manganese consistently gave increased yields. The marked increased yields of buckwheat due to iodine should be further tested before any definite conclusions are drawn. The effects of copper and fluorine appeared detrimental, at least in the amounts added.

The increased growth due to boron and zinc are not large enough to be very significant.

To obtain further evidence that manganese is essential for plant growth, buckwheat was grown in another set of cultures. Pot No. 1 contained quartz sand; No. 2, quartz sand with 200 grams of kaolin impregnated with 20 grams of calcium hydroxide; No. 3, quartz sand with 15 p.p.m. of manganese (as manganous chloride) added to the basal solution; and No. 4, quartz sand with 30 p.p.m. of manganese. The kaolin was thoroughly mixed with the calcium hydroxide by standing in contact with excess of water for one day. Then carbon dioxide was passed into the solution until all the calcium hydroxide had changed to calcium carbonate.

All the plants germinated well and no differences appeared in growth until about the eighth day. Then the plants treated with manganese, kaolin, and calcium hydroxide surpassed the control. The stalks of the latter were thicker and more rigid and the leaves larger and darker green in color.

Somewhat later the plants treated with manganese slightly sur-

passed the plants in the quartz sand culture with kaolin and calcium hydroxide. The stems appeared somewhat thicker and the leaves larger and of a deeper green color. The plants were also more rigid. However, the latter plants were no better than those obtained with kaolin alone. The slight depressing effect from the use of calcium hydroxide with kaolin is either due to neutralization of the slightly

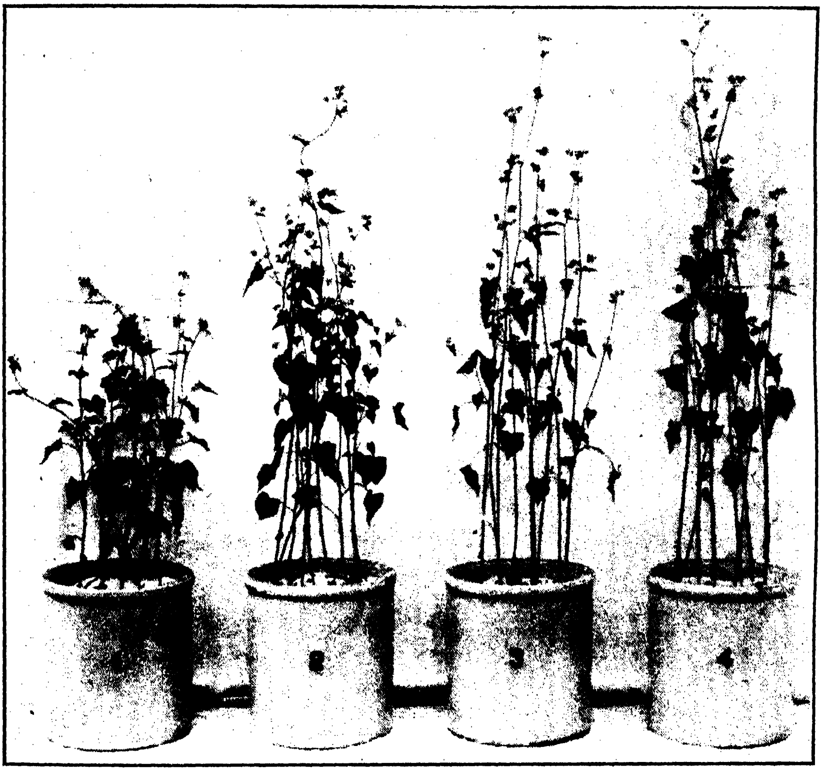

FIG. 5.—The growth of buckwheat in quartz sand cultures with complete nutrient solutions and other additions indicated. 1. Control. 2. 200 grams kaolin and 20 grams calcium hydroxide. 3. 0.015 miligram manganous chloride. 4. 0.030 miligram manganous chloride.

acidic property of the kaolin or to the fixation of manganese in difficultly soluble form. The weights of plants produced with these treatments are given in Table 8, and the general appearance is shown in Fig. 5.

The roots produced where manganese was added were as extensive as where kaolin was added.

TABLE 8.—*Effects of manganese on the growth of buckwheat in quartz sand cultures.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	4.54	0.20
2	200 grams kaolin plus 20 grams calcium hydroxide	8.10	0.76
3	0.015 gram manganous chloride	8.15	0.67
4	0.030 gram manganous chloride	9.46	0.75

INFLUENCE OF LIMESTONE WITH KAOLIN ON PLANT GROWTH

In another experiment, crushed limestone was employed to see whether it would decrease the growth of buckwheat by neutralizing the acidic property of kaolin. In this experiment, alfalfa and buckwheat were grown. The following treatments were provided in duplicate, *viz.*, quartz sand, quartz sand and 16 grams of crushed limestone, and quartz sand with 200 grams of kaolin and 16 grams of crushed limestone. To all of them the regular amount of basal nutrient solution was added.

In about 5 days, the leaves of the alfalfa with the quartz sand and kaolin had a deeper green color and were also broader. The difference in growth became greater as time went on. With the crushed limestone treatment there was no improvement over the control. At the time of harvest it was noticed that the nodules were plentiful on the roots of alfalfa where kaolin was used, but there were none present where quartz sand or crushed limestone was employed. Since the crop was not inoculated, the bacteria were undoubtedly carried by the seed. Table 9 gives the weights of the tops and roots.

TABLE 9.—*Effect of the addition of limestone and kaolin on the growth of alfalfa.*

Treatment	Weights of dry tops in grams, ave. of two	Weights of dry roots in grams, ave. of two
Control	2.00	1.25
16 grams crushed limestone	1.50	0.75
200 grams kaolin and 16 grams crushed limestone	4.06	2.50

With the buckwheat similar results were obtained. As in the case of alfalfa, the crushed limestone did not depress the growth of the buckwheat grown on the quartz sand culture with kaolin. The plants were dark green and rigid, with long internodes. The control plants were spindling and of light green color. Pot No. 2, with the addition of crushed limestone to the quartz sand, was somewhat

better than the control, but not nearly as good as the one with kaolin. The weights of the tops and roots are given in Table 10.

TABLE 10.—*Effect of the addition of limestone on the growth of buckwheat.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	Control	3.3	0.27
2	16 grams crushed limestone	5.75	0.42
3	200 grams kaolin and 16 grams crushed limestone	9.05	0.78

COMBINED INFLUENCE OF KAOLIN AND MANGANESE ON PLANT GROWTH

To ascertain whether the addition of manganese would produce as good a crop as the addition of kaolin and also whether the addition of manganese with the kaolin is advantageous, buckwheat was grown in pots of 1-gallon capacity. One-half the amount of quartz sand as well as of the basal nutrient solution was used as with the 2-gallon pots. To pot No. 1, 0.015 gram of manganous chloride was added; and to pot No. 2, 100 grams of kaolin and 0.015 gram of manganous chloride.

For the first two weeks, there were no significant differences in height with the various treatments. Later, the plants with kaolin alone pushed slightly ahead of those with kaolin and manganese, and also those with manganese alone. The plants with the kaolin treatment were somewhat thicker in stalk and the leaves somewhat larger and darker green in color than those with manganese alone. The experiment indicates that manganese added to the regular basal solution has provided conditions favorable for normal growth, and a medium nearly as good as when kaolin is added. It also indicates that kaolin may carry sufficient manganese as an impurity so that a further addition above that carried by it produces no response. The results of the experiment suggest that kaolin has some additional beneficial effect on plant growth aside from supplying manganese.

TABLE 11.—*Effect of manganese and kaolin on quartz sand culture of buckwheat.*

Pot No.	Treatment	Weight of dry tops in grams, ave. of two	Weight of dry roots in grams, ave. of two
1	0.015 gram manganese	3.28	0.422
2	100 grams kaolin	3.97	0.430
3	100 grams kaolin and 0.015 gram manganous chloride	3.54	0.427

Table 11 gives the weights of plant tissue produced. There is no significant difference in weight of roots produced.

No experimental work was done to study the effect of the colloidal property of kaolin on plant growth in quartz sand cultures. From work done in this field it seems highly improbable that the beneficial effect of kaolin is due to physical influences.

DISCUSSION

The evidence obtained in the experiments indicates that some important soil factors are often neglected in growing plants in a synthetic culture medium. The foregoing experimental evidence, as well as that of McHargue and Sommer and of Lipman and others, indicates that normal plants cannot be produced in a culture medium which contains only the usual 10 elements.

From the results obtained in the preceding experiments it is evident that marked improvements in plant growth may be obtained with manganese. What rôle it plays in the nutrition of the plant is not known. McHargue has assigned the rôle of a catalyst to manganese, and thinks it is connected with the formation of chlorophyl. Others maintain that it acts as an oxidizing agent in the soil solution, destroying toxic organic material. The writer noticed that the leaves were darker in color and the roots better developed where manganese was added to the regular basal solution. Where kaolin was added, it is probable that the deficiency of manganese was met to a certain extent. Even in the washed kaolin there were 20 p. p. m. of manganese.

Iodine gave marked beneficial effects on plant growth in quartz sand cultures. The number of cultures employed was not sufficient to allow the drawing of final conclusions as regards iodine. Aluminum also gave beneficial effects, and boron and zinc to a lesser extent. Copper and fluorine did not improve the growth of crops in quartz sand cultures.

From the work presented it appears that kaolin has a two-fold effect on the growth of plants. Judging from the marked improved root development with kaolin it seems that it has a very beneficial effect on the roots. It is possible that toxic effects from the decomposition of root hairs and root caps may be lessened or prevented by kaolin. If the toxins were basic in character, they could be taken up by the kaolin, since it is usually slightly acidic and in this way the amount of toxin in solution at any one time would be greatly lessened. In other words, the kaolin might act as a buffer against toxic material.

SUMMARY

The object of this study was to investigate some of the neglected soil factors in plant growth. It was observed in preliminary tests that when kaolin was added to the usual sand cultures better plant growth was obtained. As regards the factors involved, there appeared to be at least three possibilities, *viz.*, (a) that kaolin contains as impurities small amounts of elements other than the usual 10 which stimulate plant growth; (b) that the acidic property of kaolin in some manner benefits plant growth, possibly by combining with toxic material of a basic nature; and (c) that the colloidal property affects plant growth through physical means. Only the first two factors were studied.

Synthetic sand cultures with basal nutrient solutions, containing the usual 10 nutrient elements, were used. The work was carried on in the greenhouse under controlled conditions.

For the study of the influence of the addition of kaolin and soil to quartz sand cultures with the regular basal solutions, alfalfa, buckwheat, oats, and corn were chosen as test crops. With these crops, the kaolin materially increased the growth of the tops and usually also that of the roots. The plants in the control cultures were often spindling and pale green in color, while those grown in the quartz sand with kaolin had a thick rigid stem and were dark green in color. The leaves were also considerably larger in size. Miami silt loam had a favorable effect like kaolin only in the case of buckwheat. With the other crops, fixation of phosphate by the soil may have made phosphorus a limiting factor.

In a test with buckwheat, acid-washed kaolin gave the same results as the unwashed material. There still remained some 20 p. p. m. of manganese in this kaolin.

Treatment of the basal nutrient solution with soil and kaolin was detrimental in the case of soil but somewhat beneficial in the case of kaolin. Treatment of the distilled water used for watering with soil and kaolin was also detrimental in the case of soil and beneficial in the case of kaolin.

Boron, zinc, aluminum, manganese, copper, iodine, and fluorine were the additional elements added to quartz sand cultures besides those in the regular basal solution. Manganese consistently gave favorable results with buckwheat. Boron, zinc, aluminum, and iodine seemed beneficial, whereas copper and fluorine gave no apparent increased growth.

The use of calcium hydroxide with kaolin had a slight depressing effect on the growth of buckwheat compared to kaolin alone, ap-

parently due to the neutralization of the slightly acidic property of kaolin. However, when crushed limestone was used instead of calcium hydroxide, no depressing effects were observed.

Kaolin produced somewhat more benefit than manganese. The addition of manganese with kaolin produced no more benefit than kaolin alone. The results indicate that kaolin has some additional beneficial effect on plant growth aside from supplying manganese.

The investigation shows that kaolin, as ordinarily found, is beneficial to plant growth. Impurities in the kaolin, such as manganese, seem to account partially for the benefit. Whether or not the kaolin carries manganese in an especially suitable form for plants is not known. The slightly acidic nature of kaolin may account partially for its beneficial effect.

The results of this investigation support those of others that manganese and iodine are essential for the best plant growth.

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FROST INJURY TO SPRING WHEAT WITH A CONSIDERATION OF DROUTH RESISTANCE[1]

L. R. WALDRON[2]

A considerable amount of work has been done in regard to the relation of winter cold to the injury and survival of fall-sown wheat. It has been shown by different investigators, particularly Newton (7)[3], that there is a close correlation between winter hardiness and the colloidal condition of the plant cells. Evidently very little attention has been given to the injurious effects of spring frosts upon the young wheat (or oat or barley) plant, with a possible consequent influence upon yield. It is reasonable to presume that a study of reactions to freezing temperatures in different spring wheat varieties would show associations with colloid conditions similar to what has been found true with winter wheat varieties. If varietal variations exist in spring wheats relative to frost resistance, then certain physico-chemical differences might be looked for associated with such varia-

[1]Contribution from the Department of Agronomy, North Dakota Agricultural Experiment Station, Fargo, N. Dak. Published with the approval of the Director. Received for publication February 6, 1931.
[2]Plant Breeder. [3]Reference by number is to "Literature Cited," p. 637.

tions. Percival (9) indicates that there is no essential difference between winter and spring wheats; spring wheats survive if sown in the fall provided the winter weather is not too severe.

With winter wheats a marked difference in hardiness in varieties has always been recognized. That a similar variation has not been recognized in spring wheat is not surprising when one considers that spring wheats are subjected less severely and less frequently to the hazards of frost than are the winter varieties.

It is well recognized that the 14 haploid chromosome wheats are, on the whole, less hardy than those of the 21 chromosome group. It is rather unusual for durum wheat or its allies to show the early-growth prostrate habit, a habit of the fall-sown *T. vulgare* of those regions where severe winters are experienced. As the wheat *T. dicoccoides* found by Aaronsohn (1) in Palestine has this prostrate habit, it is probably not necessary to postulate its association with the greater hardiness of *T. vulgare* by inheritance from some species of Aegilops.

Before the introduction of the Marquis variety into the hard red spring wheat area some 20 years ago, the amount of variation toward spring frost was inconsiderable; most varieties were resistant. The introduction of early maturity into the family of varieties, along with the introduction of resistance to stem rust and to other diseases, has changed the earlier situation somewhat. Certain wheat varieties, endemic to hot countries, such as India, show marked susceptibility to frost. One of these Indian wheats, Hard Red Calcutta, was used in the production of Marquis and in this variety, compared with its other parent Red Fife, there is found a lessened degree of frost resistance.

Hayes, in the production of the variety Marquillo,[4] used the durum Iumillo as one parent. Random observations by the writer have indicated that Marquillo has less frost-resisting capacity than its Marquis parent. With regard to another variety, Hope, McFadden (6) mentions its greater susceptibility to frost compared with most other hard red spring wheats. Observations at Fargo confirm this and indicate it to be more susceptible than Marquillo. The Yaroslav emmer parent of Hope is perhaps responsible for its frost susceptibility. Clark, on the other hand, in his production of Reliance from Marquis and the winter variety Kanred, has evidently built up frost resistance in a spring wheat, for this variety possesses greater frost resistance than Marquis or even Red Fife. As a result, then, of recent breeding we possess almost certainly four recognizable grades of

[4]A history of the varieties Marquillo, Hope, Reliance, and Ceres may be found in this JOURNAL, Vol. 18: 922–935. 1926.

resistance to frost in spring wheats, and possibly five. Ranging from high to low these are Reliance, Red Fife, Marquis, Marquillo, and Hope.

Almost nothing has appeared in the literature as to the effect of frosts upon spring-sown wheat. An opinion is prevalent among observant farmers[5] that, under proper conditions a frost, acting on young wheat plants may be an advantage. It is believed that a frost at the proper time may induce increased stooling and lead to an apparent thicker stand. A benefit might result to the crop because of the frost effect upon tender weeds, but this is aside from the present study.

The tabulation[6] below shows a series of minimum temperatures in the first column, with a distribution for three localities in North Dakota of the number of years when minimum readings reached the temperatures indicated for the last two decades in May. The data cover the 30 years, 1901 to 1930, except that four years are lacking from the Langdon records. The Moorhead readings are usable for Fargo.

Temperature readings	Number of years Moorhead, Minn.	Dickinson	Langdon
Not below 30°	18	10	6
At 29°	1	2	0
28°	4	4	0
27°	1	1	3
26°	2	1	3
25°	0	1	3
24°	1	7	2
23°	1	2	3
22°	1	0	3
21°	0	1	1
20°	1	1	1
19°	0	0	1
	30	30	26

One finds increasing frequency and severity of below 30° temperatures from Fargo to Dickinson and to Langdon.

[5]Morton Page of Fargo, farm owner and manager, speaks of an instance of presumed benefit occurring in the early days when a severe spring frost seemed to be of benefit to the Red Fife variety. In 1914 he mentions a differential effect upon Red Fife and Marquis as having occurred, rather clearly indicating the more tender character of the Marquis variety. Other observations seem to verify this view relative to Marquis.

[6]Data are taken from the official U. S. Dept. of Agriculture Weather Bureau records.

EXPERIMENTAL RESULTS

The writer planted three rod-row nurseries in 1930 which carried plantings of Ceres and Hope. Two of these nurseries were located in the plant breeding garden, an area given some protection by trees and hedges. One nursery was planted about one-half mile away on an area quite unprotected. This one nursery, which was designated series 278, was planted April 8 to 10 and emergence was fairly complete by April 24. Emergence of the others, series 276 and 277, was nearly one week later. An inch of rain in April came between planting and emergence in all cases. On May 17 a minimum temperature of 26° was recorded on the college experimental plats. The Moorhead reading of the same date was 28°. Rains totaling more than 3.50 inches fell between emergence and May 17, the date of the frost. Observations after the frost showed scarcely appreciable injury to either Ceres or Hope in series 276 and 277. In series 278, on the contrary, rather marked injury was shown by the Hope variety and slight injury was shown by the Ceres. Notes were taken and the injury was found to be reasonably constant in the different check and replication plantings.

The three pairs of means from the three nurseries in bushels per acre were as follows:

	Series No. 276	Series No. 277	Series No. 278
No. of comparisons	32	45	50
Ceres	40.5±0.50	33.8±0.33	42.8±0.53
Hope	33.7±0.48	27.9±0.26	22.2±0.41
	6.8±0.69	5.9±0.42	20.6±0.67

The two series 276 and 277 were grown on the same block of ground with similar treatment previous to 1929, but 276 was grown immediately after soybeans and 277 after sugar beets. If the Ceres yields are made uniform, the results are

	Series No. 276	Series No. 277	Series No. 278
Ceres	42.8	42.8	42.8
Hope	35.6	35.4	22.2
	7.2	7.4	20.6

Ceres and Hope yielded relatively nearly the same on the two series 276 and 277. In the first set of comparisons one finds the difference between the Ceres-Hope yield of series 278 and the similar yield of series 276 to be 13.8±0.96 bushels. Evidently this difference is an

expression of the loss suffered by Hope by reason of its susceptibility to frost or because of some other factor.

The fact that Ceres and Hope were not provided with guard rows in series 278 was probably not a very disturbing factor for Hayes and Arny (5) found a lack of negative correlation between the differences in yields between border rows and adjacent rows of unlike varieties, indicating that the competition present was not a detriment to a variety. The conclusion seems reasonable that the Hope yields were very materially reduced by the frost.

Newton (7) in his study of frost resistance in wheat varieties found definite relationships between volume of press juice and hardiness, and imbibition pressure and hardiness. In one experiment, in addition to Marquis, three groups of winter wheat of known degrees of hardiness were investigated, the material being taken in a hardened condition. A regular increase of press juice with a decrease of hardiness was noted. But when the three groups of winter wheats were investigated in May, in an unhardened condition, Marquis being omitted, no relationships like the above were found. Also, it was observed by him that with the advance of colder weather in the fall resistance to the expression of sap gradually increased from zero resistance, indicating an increasing hardening of the tissues.

These points are of interest when one considers that distinct frost reaction differences are observed in the field with spring wheats. It is likely that during the seedling stage of spring-sown wheat, variations occur with regard to resistance to frost. These differences may be associated with differences in plant turgor and with other factors. Any such rapidly developed hardened condition is probably much less profound than a corresponding condition induced in winter wheats previous to cessation of growth in the fall. Studies upon selected spring wheats relative to the chemical and physical conditions associated with frost effects might furnish valuable information relative to drouth resistance.

Newton and Martin (8), in recent work upon drouth relationships of wheats and other plants, found in a series of wheats using the succulent plant tissues a considerable range of amounts of bound water. They associated the percentages of bound water directly with a presumed drouth resistance of the various wheats. This relationship, as pointed out by them, is evidently very similar to that discussed above relative to hardiness. Although pointing out this similarity, they did not follow this relationship through with the same set of plants in a combined study of frost and drouth resistance.

COMPARATIVE DROUTH RESISTANCE

The field behavior of a few spring wheats is of sufficient interest to present in this connection using the varieties Reliance, Ceres, Marquis, Marquillo, and Hope. These wheats represent perhaps four classes with respect to frost resistance. Less certainty can be expressed with regard to Ceres, but it may lie between Reliance and Marquis, thus making five classes instead of four.

A sufficient number of comparable yields are available of these varieties to be of interest.[7] If resistance to frost and drouth is related to colloidal conditions, then a wheat resistant (or susceptible) to frost might be expected to show a similar behavior towards drouth. Twenty-five comparable field-plat yields are available under conditions generally drouthy and reasonably free from stem rust, covering points in western North Dakota, in South Dakota, and in Montana. Student's method was used in determining odds. The average yields and odds are as follows:

Variety	Yields in bushels per acre	Comparison	Odds*
Ceres	16.3	Ceres-Marquis	+10,000:1
Reliance	15.1	Ceres-Reliance	60:1
Marquis	14.1	Reliance-Marquis	100:1
Marquillo	13.6	Marquis-Marquillo	7:1
Hope	12.7	Marquis-Hope	277:1
		Marquillo-Hope	34:1

*A ratio of at least 22:1 is considered necessary for significance.

With the exception of Ceres and Reliance these varieties are in the same order with respect to yield as they were placed with respect to frost resistance. The differences are significant in all cases but one, Marquis-Marquillo. The somewhat lower yield of Reliance, in comparison with Ceres, may receive an explanation in that Reliance requires a longer postheading growing period. As the season advances in July, drouth conditions, aided by heat, tend to accelerate. A wheat variety with delayed maturity perhaps suffers with greater relative intensity because it receives the drouth effect in a more drastic fashion.

Ceres and the earlier variety Reward may be compared in this

[7]The yields and other data given in this paper were secured by various experimenters and are available mainly in mimeographed and typewritten reports on file at the North Dakota Experiment Station. A portion of the information was secured by correspondence. The writer very much appreciates this help and desires to make this general acknowledgment. Individual citations seemed to be impracticable.

respect. A total of 79 Ceres and Reward field-plat experiment station yields have been compiled from various sources. Ceres usually outyields Reward, the mean difference in this series being 3.38 ± 0.34 bushels. The odds that this difference is significant are very high, being of the order $6.5 \times 10^{10}:1$. Occasionally, when drouth becomes serious—and the proper drouth factors must likely have to function—Reward either outyields Ceres or the difference in favor of Ceres is less than 1 bushel. There are 21 such cases out of the 79. The foregoing is given mathematical expression in the following manner. The correlation between the Ceres yields and the Ceres-Reward differences was found to be 0.76 ± 0.03. This represents the absolute relation between the two variables. In other words, the differences increase as the Ceres yields increase. There is nothing in this coefficient to show the relative behavior of the Ceres-Reward differences for different values of the Ceres yields.

The formula proposed by Harris (4)[8] for a coefficient to measure the correlation between a variable and the deviation of a dependent variable from its probable value was found to be usable in this case. The Ceres-Reward differences in this instance constitute the dependent variable. The formula given by Harris is

$$r_{xz} = \frac{r_{xy} - V_x/V_y}{\sqrt{1 - r_{xy}^2 + (r_{xy} - V_x/V_y)^2}},$$ where r_{xy} is the correlation coefficient with which one is dealing and V_x and V_y are the coefficients of variability of the two variables. The coefficient r_{xz}, calculated from the coefficients of variability and the correlation coefficient given above, was found to be $r_{xz} = -0.23 \pm 0.07$. This just shows significance, but the change from the correlation $r_{xy} = 0.76$ is very considerable. The import of this coefficient, $r_{xz} = -0.23$, is that as the Ceres yields tend to decrease in size the lead of the Ceres variety over the Reward tends to lessen. With lower Ceres yields, indicating drouthier conditions in the experiments cited, the Reward variety tends to reap an advantage, doubtless because of its greater earliness. Something similar to this may occur when Reliance and Ceres are considered.

The data available at present are scarcely sufficient to decide the point. The relative behavior of Ceres and Reliance in North Dakota and in Montana may be instanced. The two wheats yield the same in Montana, while in western North Dakota Ceres has significantly outyielded Reliance. The Montana minimum temperatures during the growing season are lower than in North Dakota. The longer postheading period seems to act adversely in adverse seasons.

[8]The formula as given in Genetics, 3: 329, is printed wrong; compare the above.

DROUTH RESISTANCE OF DURUM WHEAT

A conception is prevalent in many quarters that durum wheat, *T. durum*, is particularly drouth resistant. Carr (2) reflects this opinion when he states in effect that the introduction of durum wheat made wheat growing possible in areas too arid for the successful growing of common wheat. But Stoa, *et al.* (13), in their durum wheat map for North Dakota, the major state for this wheat, show durum to be of least relative importance in the western portion where the rainfall is least. The problem has recently been attacked from a scientific angle by Newton and Martin (8). As already mentioned, they listed a number of wheat species and varieties with respect to bound water found in the press juice, averaging the results of two years. Three wheats taken from their Table 26 are as follows:

	Bound water, %
T. dicoccum (var. emmer)	7.2
T. durum (var. Kubanka)	7.0
T. vulgare (var. Marquis)	4.1

Their measures for drouth resistance between emmer and Kubanka, on the one hand, and Marquis, on the other, show considerable difference. It is important to correlate the above data with empirical results from the field, but evident difficulties will be met in any attempt of this sort.

There are now available a fairly large number of field-plat yield comparisons between Marquis and Kubanka from a semi-arid region, with stem rust usually a minor factor. There are 54 such comparisons from four localities in western North Dakota, *viz.*, Mandan[9], Dickinson, Williston, and Hettinger. In 28 of the 54 comparisons Kubanka was the heavier yielder. The excess yield of Kubanka was 1.12 ± 0.27 bushels. The odds in favor of Kubanka, as the highest yielding of the two, are about 145:1. It is necessary to subject these yields to a closer analysis with regard to the effect of rust. At Dickinson careful data are available, taken by Clark for 1913 and by Smith for the next 17 years. These notes indicate that rust was present during 5 of the 17 years in sufficient intensity to offset any effect of drouth resistance. At Mandan only one year's results should be eliminated because of rust. The yields for these six crop years are as follows:

	Kubanka	Marquis	Difference
1915 Dickinson	46.8	32.8	14.0
1916 Dickinson	16.9	13.5	3.4
1920 Dickinson	23.6	15.9	7.7
1923 Dickinson	22.9	18.3	4.6
1927 Dickinson	24.2	18.2	6.0
1927 Mandan	21.5	15.4	6.1

[9]The Mandan data are used through the courtesy of the U. S. Dept. of Agriculture.

If these six crop years are omitted, a much better measure will be secured of the inherent yielding capacity of the two wheats under semi-arid conditions. When this is done the mean of the difference becomes 0.39 ± 0.26, indicating no significant difference. There are 20 comparable yields from three Montana points between Kubanka and Marquis grown under dry-land conditions, at Moccasin, Havre, and Huntley. In this case Marquis is slightly ahead, the mean difference being 0.56 ± 0.36. The difference is not significant. If the total 68 crop-year yields are considered, the mean difference, in favor of Kubanka, is but 0.11 ± 0.21 bushel. This mean is but one-half the probable error. A tabulation of these differences is as follows:

Locality	No. of trials	Kubanka-Marquis	Odds‡
Western North Dakota	54*	1.12 ± 0.27	145:1
Western North Dakota	48†	0.39 ± 0.26	2:1
Montana	20	-0.56 ± 0.36	3:1
Western North Dakota and Montana	68†	0.11 ± 0.21	—1:1

*Rust years included. †Rust years excluded.
‡A ratio of at least 22:1 is considered necessary for significance.

The area selected is probably the best available to measure the drouth resistance of a durum wheat. The finding is apparently negative for Kubanka. This result does not deny the possibility of Kubanka and the other durums being potentially drouth resistant. Some other factor, such as susceptibility to certain diseases, may be operating to offset the assumed durum drouth resistance which might manifest itself under a more favorable environment.

In connection with the preceding discussion the question arises as to the "inherent" yielding capacity of Kubanka wheat in relation to Marquis. One may question if wheats have any yielding capacity of this sort as yields are impossible without an environment. A statement something like the following seems warranted: Certain varieties of durum wheat, typified by Kubanka, when grown in the more humid portions of North Dakota, have a capacity for yield fully equal to that of Marquis. In the Langdon area especially, Kubanka has uniformly and rather decidedly outyielded Marquis. This larger yield has been due in part to the greater rust injury suffered by Marquis, but aside from that factor the durum varieties grown there likely are normally higher yielding, under that environment, than is Marquis.

CORRELATION STUDIES

A few correlations were calculated using the 54 western North Dakota yields. The correlation between yields of Kubanka and the

Kubanka-Marquis differences was found to be 0.31±0.08. Apparently one might expect a negative correlation if Kubanka were to act in a more favorable manner under low yield, or dry season, conditions. The formula of Harris (4) was used in this instance also and the value of $r_{xz} = -0.59 \pm 0.06$. This indicates that as the Kubanka yields lessen the Kubanka-Marquis differences lessen not only absolutely but relatively in proportion to the decrease of Kubanka. In other words, this coefficient seems to indicate that Kubanka performs less efficiently relative to Marquis in years of low yields, and presumably drier weather, than in years of good yield.

The correlation of the Kubanka yields to the annual precipitation, August 1 to July 31, was found to be 0.40±0.08 and to the April-July precipitation, 0.37±0.08. Each of these shows significance but not of a high order. These rather low correlations may indicate that considerable of the precipitation was not well utilized by the crop.

The length of growing season has an influence upon yield and under semi-arid conditions the difference in time of development between Marquis and Kubanka may be of importance. Data taken by Clark and Smith at Dickinson, covering 18 years, are available. The days from emergence to heading and from heading to maturity are as follows:

	Emergence to heads	Diff.	Odds	Heads to maturity	Diff.	Odds
Kubanka	68.6			30.1		
Marquis	67.7	0.9	27:1	27.2	2.9	+10,000:1

Kubanka is distinctly a longer season wheat. This is particularly marked for the second period, from heading to maturity. In no instance did Marquis require the longer postheading period.

Temperature conditions evidently have a more immediate and striking effect than does precipitation. Correlation coefficients were calculated for the 18 years, 1913 to 1930, between the mean July maxima at Dickinson and four characters as follows:

	Constants
July mean maxima and Kubanka yields	—0.80±0.06
July mean maxima and Kubanka-Marquis yields	—0.48±0.12
July mean maxima and Kubanka postheading periods	—0.73±0.08
July mean maxima and Kubanka-Marquis postheading periods	0.08±0.16

That July maximum temperatures have a very decided effect upon yield is shown by the negative correlation of —0.80±0.06. The July maxima were correlated with the Kubanka excess yields over Mar-

quis. The correlation was found to be —0.48±0.12. This means that with high temperatures the lead of Kubanka over Marquis tends to decrease. A significant positive correlation might be expected here, assuming Kubanka to be drouth resistant. Drouth is generally associated with hot weather, although the effect of the two factors drouth and heat are often not easily separated.

High July maximum temperatures markedly influence the length of the Kubanka postheading period which is a common observation with any wheat variety. We have a negative correlation in this instance of —0.73±0.08. The July maximum temperatures were correlated with the excess of the Kubanka postheading periods over Marquis. The nearly zero correlation indicates that Kubanka did not benefit over Marquis in weathering the attacks of heat.

YIELDS OF EMMER

Inasmuch as Newton and Martin found emmer and Kubanka durum to yield essentially the same percentages of bound water, it is of importance to compare their behavior in the field. Comparisons between yields of emmer and durum wheat are far less extensive than comparisons between durum and common wheat. A particularly long series of yields is available from Dickinson where Kubanka durum and the rust-resistant Yaroslav emmer have been grown since 1907 with compilations of yields by Smith (12). As two years are missing, 22 comparisons are available. While for some of the years the wheat and emmer were not grown in the same experiment, the experiments which contained them were so closely allied that the two crops sampled a closely restricted environment and any advantage accruing to one crop one year would likely be offset another year by the theory of probability.

Schollander (11) and Ruzicka (10) present emmer yields from the Williston Experiment Station for the 12 years, 1908 to 1920, with the 1919 yields not included. Detailed typewritten reports for the 9 years, 1909 to 1917, by the cerealist F. R. Babcock, filed at the North Dakota Experiment Station, indicate that the two crops, Kubanka durum wheat and emmer, were sown comparably for these years, except in 1911, and as the comparability at harvest of the 1913 yields is somewhat in question 1911 and 1913 have been omitted. Detailed statements are lacking relative to the 1918 and 1920 crops, but these are included. Two emmer strains were grown at Williston, N. Dak., *viz.*, 305 until 1913 and C. I. 1524 from 1914 on.

When emmer is threshed the grain carries more or less hull, depending on conditions. Henry and Morrison in their *Feeds and*

Feeding state that about 21% of the threshed emmer grain is composed of hull. Champlain and Morrison (3) state that the average hull under South Dakota conditions can be figured as about 25%. The conservative figure of 20% will be assumed for this discussion. The 22 Dickinson and 10 Williston average yields are shown in the following tabulation, in pounds per acre:

Locality	No. of years	Crop	Threshed grain	Hull-free grain
Dickinson	22	Kubanka	1,214	1,214
		Emmer	1,410	1,128
Williston	10	Kubanka	1,681	1,681
		Emmer	1,780	1,424
Average		Kubanka		1,360
		Emmer		1,221

The difference in favor of Kubanka as an average of 32 crop years from two localities in western North Dakota is 139 pounds of clean grain per acre, a difference too small to be of significance considering the variability of the individual yields. The evidence, so far as it goes, does not lend itself to the belief that emmer is of greater drouth resistance than Kubanka durum. It seems reasonable to conclude, then, that neither Kubanka durum wheat nor emmer show greater drouth resistance than Marquis.

SUMMARY

Recent breeding work has brought into existence wheat varieties more susceptible to frost than any that were grown 15 or more years ago.

While injury of the wheat crop by spring frost is unusual, it may occur. Data from three experiments indicate that yields of Hope wheat were reduced by frost about 13.8 bushels, or 38%.

Five wheat varieties are arranged tentatively in order of their resistance against frost. Yields of these varieties under semi-arid conditions show, in general, a positive relationship between frost and drouth resistance.

Recent studies of drouth resistance of Kubanka durum and Marquis are cited and yields are given of these two wheats under drouth conditions. Kubanka does not show a yield significantly higher than that of Marquis. The difference for 68 comparable yields of Kubanka and Marquis, omitting years when rust was a factor, is 0.11 ± 0.21 bushel.

Correlation coefficients do not indicate greater drouth resistance in Kubanka than in Marquis, but rather the contrary. Long post-heading periods affect yields adversely in severe seasons.

An average of yields for 32 crop years from Kubanka and emmer secured at Dickinson and at Williston, North Dakota, shows the grain-yielding capacities of the two crops to be about identical under semi-arid conditions so far as those points are representative.

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CORRELATION BETWEEN YIELDS OF WINTER WHEAT VARIETIES GROWN IN VARIOUS LOCATIONS IN THE COLUMBIA BASIN OF OREGON[1]

J. FOSTER MARTIN AND D. E. STEPHENS[2]

Several outlying cereal nurseries[3] were established in the Columbia Basin counties of Oregon in 1924 and 1925 to determine (1) the correlation between yields at Moro and other points, and (2) the best varieties for each locality. The location of the nurseries is shown in Table 1.

Winter wheat, spring wheat, barley, and oats have been grown in these nurseries. More varieties of winter wheat were grown than of all other grains combined and in this paper yields of winter wheat only are considered.

Since its establishment in 1909, the Sherman County Branch Station at Moro has been testing cereal varieties by both the replicated field-plat and nursery-row methods. New and improved varieties have been distributed as a result of these trials. With few exceptions, varieties that have proved superior in station trials also have proved superior on farms. A complete agreement would not be expected because of rather marked differences in elevation, temperature, precipitation, and soil depth within comparatively short distances in the Columbia Basin area.

Average annual precipitation varies from about 7 to more than 20 inches in the Columbia Basin. The mean annual precipitation at Moro is 11.45 inches. Winter wheat, the most widely grown crop, is raised on soils varying from 1 to 8 feet or more in depth.

In addition to affording opportunities for observing a large number of grain varieties growing under varying conditions, these outlying nurseries also have been a means of creating greater interest among farmers in the work of the Moro station.

MATERIAL AND METHODS

The nursery, rather than field plats, was selected as the best method for making this study. Time required to do the seeding and harvesting, the ability to test more varieties, and the availability of

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[3]These nursery experiments were conducted by B. B. Bayles in 1925 and 1926 and by G. A. Mitchell in 1927.

land and equipment determined this choice. The same cereal varieties have been grown for many years at Moro in replicated field plats and in nursery rows. A high degree of correlation has been found to exist between the relative rank of the varieties grown by the two methods. A correlation coefficient of $+0.712 \pm 0.096$ was obtained between the yields in the plats and nursery of 12 varieties of winter wheat grown at Moro during the 5-year period, 1924–28, inclusive. Stringfield[4] compared the variation from average rank for cereals grown in nursery rows and in field plats and concluded that variability probably is not significantly lower for the field plats than for the nursery rows.

County agents, in most cases, arranged for suitable land, which was furnished by interested farmers. Varieties grown in the outlying nurseries were selected from those giving the most satisfactory results at the Moro station. Some varieties were discarded and some additions were made, but 43 varieties were grown in each nursery for 2 or more years.

Several rows were marked at a time by dragging a bar with pegs attached at 1-foot intervals. Seeding was done with a Planet Jr. garden drill, using a weighed quantity of seed. Experiments conducted at Moro show that there is little difference in yield between a 2-peck and an 8-peck rate of seeding if uniform stands are obtained.

The varieties were grown in triplicate 3-row blocks, each 1 rod long. All three series of each variety were sown consecutively to avoid unnecessary cleaning of the drill. The alleys were sown to eliminate border effect but were harvested before the plats were cut.

The center row only of each 3-row block was harvested for yield. The bundles were wrapped with paper to prevent loss of shattered grain and were hauled by truck to Moro for threshing.

A nursery of 40 varieties can be marked, seeded, and labelled in approximately 3 hours by one man. One man can readily cut 40 to 50 rows an hour with a hand sickle and the bundles can be wrapped considerably faster than they can be cut.

In order to give some idea as to the variability, probable errors of the experiments for each nursery for the years 1927 and 1928 were calculated by the deviation from the mean method as corrected by Student. The probable error in bushels was changed to probable error in per cent by dividing by the average yield of all varieties and multiplying by 100.

[4]STRINGFIELD, G. H. Types of field and plat in crop tests. Jour. Amer. Soc. Agron., 20: 1073–1096. 1928.

DISCUSSION OF RESULTS

PROBABLE ERRORS

Table 1 shows the probable errors of the experiment calculated for each nursery.

Some of the probable errors are rather high. Soil heterogeneity and uneven winterkilling because of variability in snow covering account for most of the differences. As each nursery has occupied a portion of a farm field, some difficulty also has been encountered with livestock, rodents, and pheasants.

TABLE 1.—*Probable errors in seven wheat nurseries grown in eastern Oregon in 1927 and 1928.*

Nursery	Probable error %	
	1927	1928
Moro	7.63	8.84
Pendleton	6.90	4.27
Eightmile	5.87	8.33
Lexington	4.19	6.35
Condon	4.65	6.29
Kent	5.12	14.47
Wasco County	9.14	10.21

The nursery plat at Moro slopes gradually towards more shallow soil, so the three series were not on soil of the same depth and productivity. However, a correlation exists between the yields of varieties in the different series, which lessens the significance of the rather high errors. A draw running across the Pendleton nursery in 1927 caused the results to be a trifle irregular, but the data were still of considerable value.

A probable error of 8.33% was obtained for the nursery at Eightmile in 1928. Low rainfall in the late spring caused grain on shallow spots to "fire" and may account for the large error. The data for the nursery at Kent in 1928 are more accurate than the high probable error indicates. All of the third series was on shallow soil. Consequently, the yields were much lower than those of the other two series, although comparatively the varieties ranked about the same.

Considerable variability has characterized the nurseries in Wasco County. A combination of rodents and variable soil depth made accurate varietal testing difficult. This explains the large probable errors of 9.14% and 10.21% for the two years.

RANK OF VARIETIES

Table 2 shows the average rank and the number of years under test of 43 wheat varieties and strains grown at seven locations in eastern Oregon. The rankings are comparable, as the yield of each

variety is based on its percentage yield of the check variety for the years grown. The varieties, with a few exceptions, were well adapted to the conditions under which they were grown. Most of the varieties would be classed either as hard red winter or as white wheats.

Because of its winterhardiness and ability to produce under adverse conditions, Turkey wheat is more widely grown than any other variety in the drier sections of the Columbia Basin. The ranks of varieties in Table 2 indicate, however, that there are several varieties more desirable on the basis of yield than the Turkey types. Strains of the hybrids Fortyfold x Federation, Arcadian x Hard Federation, Forty-fold x Hard Federation, and Fortyfold x Hybrid 128 gave high yields at all stations. At least two of the three highest yielding strains in each nursery were some of these hybrids. This indicated a general agreement of results among the localities. With a single exception, however, the same strain did not rank first at any two stations.

A few varieties did well in certain localities because of special conditions or characteristics. Federation and Pacific Bluestem, with a spring-growth habit and not winter hardy, ranked high at Eightmile probably because there was a protective blanket of snow every winter. Blackhull, chiefly because of early heading which allows it to escape drought, yielded well at Kent where the soil is shallow.

YIELD CORRELATIONS

One purpose of conducting these experiments was to determine whether sufficient correlation existed between results at Moro and those in other localities to make it safe to consider Moro results applicable to the entire Columbia Basin. The yield of each variety for the period grown was expressed as a percentage yield of Kharkof, the standard variety, and correlation coefficients were calculated from these percentages. This method seemed the most desirable because all of the varieties were not grown for the same number of years at each nursery, as shown in Table 2.

Table 3 lists the coefficients of correlation between yields of nurseries included in the experiment.

Considering three times the probable error to be significant mathematically, 14 of the 21 coefficients are significant in relation to their probable errors. This indicates that a fair measure of the value of wheat varieties in various parts of the Columbia Basin can be obtained from experiments in a single locality. Four of the nonsignificant coefficients are for the Wasco County nursery where conditions for the experiment have been very unsatisfactory.

TABLE 2.—*Relative rank of 43 winter wheat varieties and the number of years each has been grown at seven nurseries in eastern Oregon.*

Variety or strain	C. I.* No.	Nursery No.	Moro		Pendleton		Eightmile		Lexington		Condon		Kent		Wasco County	
			Rank	Years grown	Rank	Years grown	Rank	Years grown	Rank	Years grown	Rank	Years grown	Rank	Years grown	Rank	Years grown
Hard Red Winter																
Kharkof	8249	—	29	5	19	5	39	4	29	5	19	2	28	3	15	5
Argentine	1569–2	—	25	5	23	5	43	4	33	5	21	2	39	3	18	5
Regal	7364	—	25	5	29	5	38	4	33	5	28	2	34	3	13	5
Kanred	5146	—	41	5	6	5	30	4	40	5	31	2	25	3	22	5
Turkey x Bearded Minn	8243	—	35	5	37	4	35	4	38	4	15	2	28	3	39	4
Blackhull	6251	—	18	5	13	4	29	3	18	4	43	2	1	3	25	4
Oro	8220	—	20	5	21	5	41	3	29	3	26	2	36	3	10	5
Defiance	—	373–141	12	5	8	2	36	2	39	2	16	2	27	2	5	2
Ridit	6703	—	38	5	32	5	42	4	40	5	35	2	41	3	33	5
Kanred x Marquis	8245	—	23	5	17	4	6	3	20	4	12	2	15	3	26	4
Soft Red Winter																
Triplet	5408	—	15	5	11	5	4	4	15	5	3	2	31	3	7	5
White																
Turkey x Florence	—	935	28	5	34	5	40	3	37	3	24	2	38	3	11	4
P 1068 x Preston	—	5896–3–2	27	2	40	2	31	2	10	2	40	1	22	2	5	2
P 1068 x Preston	—	5896–3–6	11	5	33	5	37	4	7	5	4	2	13	3	23	5
P 1068 x Preston	8244	—	16	5	26	4	27	3	17	4	33	2	5	3	29	4
White Odessa	4655	—	4	5	25	5	26	4	14	5	8	2	31	3	28	5
Federation	4734	—	22	5	41	5	2	4	27	5	10	2	9	3	37	5
Pacific Bluestem	4067	—	41	5	42	5	9	4	33	5	21	2	26	3	43	5
Jenkin	5177	—	33	5	21	5	18	4	27	5	38	2	37	3	32	4
Hybrid 128	4512	—	6	5	14	5	15	4	23	5	18	2	22	3	11	4
Hybrid 143	4513	—	16	5	8	3	19	3	31	4	33	2	4	3	34	4
Hybrid 63	4510	—	33	5	16	4	12	3	8	4	8	2	17	3	14	4
Albit	8275	—	38	2	17	2	28	2	19	2	29	2	24	2	15	2

Portyfold	4156	—	43	5	43	4	23	4	43	5	41	2	42	2	42	5
Portyfold x Hybrid 128	———	938	12	5	11	5	24	3	23	4	19	2	31	3	8	4
Portyfold x Hybrid 128	———	942	12	3	4	5	22	3	4	3	12	2	14	3	26	4
Portyfold x Hybrid 128	8251	—	19	5	15	3	24	3	12	3	39	2	12	3	20	3
Portyfold x Hybrid 128	———	945	5	3	4	2	12	2	12	2	37	2	10	2	3	2
Portyfold x Hard Federation	8248	—	32	5	28	4	7	3	16	3	7	2	15	3	30	4
Portyfold x Hard Federation	———	964	1	3	20	2	14	2	2	2	2	2	11	2	19	2
Portyfold x Hard Federation	———	965	3	3	30	2	5	2	1	2	23	2	28	2	31	2
Portyfold x Hard Federation	———	967	21	3	34	2	10	2	42	2	11	2	18	2	4	2
Portyfold x Federation	8247	—	10	5	3	5	1	3	6	3	5	2	2	3	38	4
Portyfold x Federation	———	980	23	3	1	2	16	2	11	2	1	2	3	2	17	2
Portyfold x Federation	———	983	7	3	36	2	20	2	21	2	35	2	20	2	36	2
Federation x Arcadian	———	969	40	3	38	2	33	2	26	2	25	2	8	2	41	2
Arcadian x Hard Federation	8246	—	2	5	10	4	7	3	9	3	31	2	19	3	40	4
Arcadian x Hard Federation	———	977	7	3	7	2	3	2	3	2	6	2	6	2	1	2
Arcadian x Hard Federation	———	979	9	3	2	2	11	2	5	2	14	2	7	2	23	2
Hybrid 128 x White Odessa	———	948	36	4	23	2	32	2	32	2	42	2	21	2	9	2
Hybrid 128 x White Odessa	———	949	37	4	39	3	21	3	36	3	30	2	40	3	35	3
Hybrid 128 x White Odessa	———	950	31	4	31	3	34	3	22	3	26	2	43	2	20	3
Hybrid 128 x White Odessa	———	953	30	4	27	2	17	2	25	2	17	2	35	2	1	2

*C. I. refers to accession number of Division of Cereal Crops and Diseases.

TABLE 3.—*Coefficients of correlation between the yields of varieties of winter wheat grown at seven localities in eastern Oregon for periods varying from 2 to 5 years.*

Nursery	Pendleton	Eightmile	Lexington	Condon	Kent	Wasco County
Moro	0.479 ± 0.079	0.253 ± 0.096	0.686 ± 0.054	0.369 ± 0.089	0.401 ± 0.086	0.272 ± 0.095
Pendleton	———	0.196 ± 0.099	0.447 ± 0.082	0.383 ± 0.088	0.520 ± 0.075	0.401 ± 0.086
Eightmile	———	———	0.439 ± 0.083	0.365 ± 0.089	0.416 ± 0.085	0.430 ± 0.084
Lexington	———	———	———	0.503 ± 0.077	0.447 ± 0.082	0.145 ± 0.101
Condon	———	———	———	———	0.266 ± 0.096	0.177 ± 0.100
Kent	———	———	———	———	———	0.001 ± 0.103

As stated before, climatic and soil conditions in the Columbia Basin are highly variable, and an extremely high degree of correlation would not be anticipated.

Wright[5] concludes that "it would often be desirable to use a method of analysis by which the knowledge that we have in regard to causal relations may be combined with the knowledge of the degree of relationship furnished by the coefficients of correlation." This point is important in properly interpreting the results reported in this paper.

The results at Moro and Pendleton have a correlation coefficient of 0.470 ± 0.079. Pendleton is in a locality of deeper soil and higher rainfall than Moro. Because Pendleton has more snow during the winter months, there is usually less winter injury than at Moro. In years with little winter injury at Moro there is a higher correlation between yields at Moro and Pendleton than that shown above.

The correlation between yields at Moro and Eightmile was only 0.253 ± 0.096. The correlation is low because sufficient snow covering every year enabled nonhardy varieties to come through the winter with good stands at Eightmile. Federation, Pacific Bluestem, and Jenkin, which are spring wheats in growth habit, were not injured and were much higher in yield at Eightmile than at Moro. Fortyfold is one of the lowest yielding varieties at Moro, partly because of its susceptibility to shattering. It yields fairly well at Eightmile, where there is less wind and consequently less loss from shattering.

Yields at Moro and Lexington are significantly correlated, as evidenced by the coefficient 0.686 ± 0.054. Soil texture, elevation, and rainfall are similar in the two locations. The soil at Moro is slightly deeper. The yields at Moro usually were higher, but the relative rank of the varieties was not affected to any great extent. Possibly the nursery at Lexington could be eliminated safely because of the similarity to the results obtained at Moro.

The coefficient of 0.369 ± 0.089 between yields at Moro and Condon is not so high as would be expected were the conditions not known. Condon yields were calculated on the basis of 2 years of high production. Moro results are taken over a longer time, in which 1 or 2 years of low wheat production are included. Late-maturing varieties do not yield well in poor years. This fact, along with others, causes the relative rank to fluctuate from year to year. Ordinarily, results are more variable at Condon.

The correlation coefficient between yields at Moro and Kent is 0.401 ± 0.086. Although Kent is only 25 miles from Moro, the yields

[5]Wright, S. Correlation and causation. Jour. Agr. Res., 20: 557–585. 1921.

at the two places vary widely in dry seasons. The soil at Kent is too shallow to store sufficient moisture to mature a good crop. Consequently, the wheat is largely dependent upon late spring rains. Without these rains the yields may be too low to pay for cost of production. Under such conditions, early maturing varieties give the better yields, while many late varieties scarcely head at all. In favorable years, results at Moro and Kent are similar.

The low coefficient of 0.272 ± 0.095 between results at Moro and Wasco County is largely caused by the unsatisfactory nature of the Wasco County trials. Results were altered by rodents and other conditions difficult to control.

Coefficients of correlation have been calculated between the results of each two nurseries included in the experiment. They are about what normally would be expected except that the correlations having Wasco County as one member are not consistent. Reasons for this are obvious from a consideration of the previous discussion regarding this nursery. A correlation of —0.430 ± 0.084 was obtained between yields at Eightmile and Wasco County. This figure has little significance because of the variability of the Wasco County trials. A low correlation is to be expected because of the differences in snow covering at the two places. The coefficient of 0.520 ± 0.075 between yields at Pendleton and Kent is too high in comparison to the others. This is largely caused by the yields of six varieties being relatively high at both nurseries because of early maturity and high yielding capacity. When the results of these six varieties are not included the correlation coefficient drops to less than 0.3.

The correlation of yields at Moro with those of the other nurseries for a 2-year average are presented in Table 4.

TABLE 4.—*Coefficients of correlation between average yields at Moro and at six other nurseries for a 2-year period.*

Localities	Coefficients
Moro-Pendleton	0.406 ± .085
Moro-Eightmile	0.310 ± .092
Moro-Lexington	0.582 ± .067
Moro-Condon	0.356 ± .089
Moro-Kent	0.416 ± .084
Moro-Wasco County	0.490 ± .078

The figures coincide rather closely with those given in Table 3, and indicate that a 2-year period may give results of value for yield comparisons except that differences caused by severe winters and drought may not be accounted for. These results, as well as those shown in Table 3, indicate that although a rough measure of the

adaptation of varieties in other localities can be obtained from the Moro results, none of the nurseries, with the possible exception of the one at Lexington, can be safely eliminated. A higher and more nearly correct correlation was obtained for Moro and Wasco County in the 2-year period. The nursery in Wasco County was grown under less variable conditions during the years in which these results were obtained.

SUMMARY AND CONCLUSIONS

Climatic conditions and soil depth differ considerably in various sections of the Columbia Basin of Oregon. Experiments were conducted to determine the best variety to grow in each section, and the correlation between results at Moro and the other localities.

Varieties were tested by the nursery method in triplicated 3-row blocks.

Soil heterogeneity, uneven winterkilling, and other factors caused some of the probable errors to be high. They range from 4.19 to 14.47%.

Strains of the hybrids Fortyfold x Federation, Arcadian x Hard Federation, Fortyfold x Hard Federation, and Fortyfold x Hybrid 128 gave the highest average yields.

Correlation coefficients were calculated between yields from all possible pairs of the seven nurseries included in this report. Fourteen of the 21 correlation coefficients are significant in relation to their probable errors. Four of the coefficients lacking significance are concerned with Wasco County where conditions for the experiment were not satisfactory. Most of the others are about what would be expected from a knowledge of soil and climatic conditions in each locality.

Coefficients of correlation between the results at Moro and those at the other nurseries for a 2-year period indicate that a 2-year average is of value except that differences caused by severe winters and drought may not be accounted for.

Although difficulties encountered with rodents, pheasants, etc., are emphasized more in nursery than in field-plat trials, the varieties rank close to expectancy when all factors are considered.

The data indicate that, with the possible exception of the nursery at Lexington where results closely parallel those at Moro, the outlying nurseries in the Columbia Basin should be continued.

THE RELATIVE YIELD OF A FIRST GENERATION CROSS BETWEEN TWO VARIETIES OF CORN BEFORE AND AFTER SELECTION[1]

R. J. GARBER AND H. F. A. NORTH[2]

In Bulletin 199 of the West Virginia Agricultural Experiment Station is discussed a first generation variety cross of corn, the yield from which exceeded that of either parent. The crossed seed was produced, as is usual in such cases, by interplanting the varieties and detasseling one of them. The crossed seed so obtained and the seed of the parent varieties were planted in adjacent plats to determine the relative yields. The plats were quadruplicated in all tests except one in which they were triplicated. There were three tests carried on from 1922 to 1924, inclusive, in different sections of the state.

The first generation cross referred to was Clarage x Longfellow. Clarage is a yellow dent corn that at Morgantown requires about 150 days to mature, whereas Longfellow is a flint corn that requires only 130 days to mature. Seed of Clarage was obtained from F. E. Eichelberger, Washington Court House, Ohio, and seed of Longfellow from R. Keeler, Bridgewater, Connecticut.

RELATIVE YIELD OF AN F_1 VARIETAL CROSS BEFORE SELECTION

In Table 1 the yields of the first generation cross and of the parent varieties are shown. Further details may be obtained from the bulletin mentioned above. It is obvious that the yield from the first generation cross exceeded the average yield of either parent. In fact in only one of the nine tests did the higher-yielding parent produce more than the first generation cross, *viz.*, in 1922 the four plats of Clarage grown in Randolph County gave an average yield of 57.8 bushels per acre and the same number of plats of Clarage x Longfellow gave an average yield of 51.5 bushels per acre.

From the data it seemed reasonable to conclude that here was an instance where a first generation cross between two varieties of corn possessed greater yielding ability than the higher-yielding parent. Not only did the first generation cross produce somewhat greater yields, but it matured earlier than Clarage, the later parent.

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director. Received for publication February 6, 1931.

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RELATIVE YIELD OF AN F_1 VARIETAL CROSS AFTER SELECTION

The suggestion was made that possibly the first generation cross would not show the same relative increase in yield over the parent varieties if the latter were first selected for high yield. To test this hypothesis two lots of seed ears were obtained from the same sources as those used in previous experiments. In 1927 an ear-to-row test was made of 200 ears of Clarage and of 200 ears of Longfellow.

TABLE 1.—*Yields of a first generation cross, Clarage x Longfellow, and the parental varieties.*

Varieties	County where grown	Yield in bushels per acre			
		1922	1923	1924	Average
Clarage x Longfellow	Greenbrier	39.1	45.5	15.0	33.2
Clarage	Greenbrier	36.9	38.4	7.6	27.6
Longfellow	Greenbrier	7.9	16.5	9.3	11.2
Clarage x Longfellow	Mercer	38.8	41.4	38.4	39.5
Clarage	Mercer	34.2	34.7	—	34.5*
Longfellow	Mercer	26.6	21.0	27.7	25.1
Clarage x Longfellow	Randolph	51.5	43.1	33.3	42.6
Clarage	Randolph	57.8	34.7	25.4	39.3
Longfellow	Randolph	22.7	18.4	—	20.6*

*Two-year averages only.

Such rows were planted in duplicate and the yields determined on a water-free basis. Longfellow was badly infected with root rot so probably rows that proved most resistant to root rot were the ones that produced the highest yields. Remnants of the 25 seed ears of each variety that gave the greatest yields were mixed separately. A part of the seed of each mixture was planted in alternate rows in a crossing plat in 1928 to obtain crossed seed. The remainder of the mixed seed was saved for the comparative yield trials.

In 1929 the crossed seed and the remnant seed of the 25 highest yielding ears of each variety in the ear-to-row test were planted in adjacent plats on the agronomy farm at Morgantown. A plat consisted of three rows with the corn planted in hills 3 feet, 6 inches each way. Four to five seeds per hill were planted and later the hills were thinned to two stalks. The middle row only was used for the yield determinations. Plats 1 to 24, inclusive, were 88½ feet long and plats 25 to 33, inclusive, were 115 feet long. The hills at the ends of the plats were discarded. The planting plan, together with the yields expressed in terms of bushels of dry (14% moisture) ear corn per acre, is shown in Table 2. It will be noted that there were 11 replicated plats of each variety and of the first generation cross.

It is apparent from Table 2 that considerable variation in yield, even within the same variety, was obtained. It is also obvious

from the yields of Clarage and of the first generation cross that there was a positive correlation between the productivity of adjacent plats. There seems to have been a more or less gradual decrease in productivity from the lower- to the higher-numbered plats. For this reason adjacent plats were paired and the analysis of the difference in yield made according to Student's method.

TABLE 2.—*Planting plan and yields of a first generation variety cross in corn, together with the parent varieties, on the agronomy farm in 1929.*

Variety	Plat No.	Yield in bushels of dry ear corn per acre	Variety	Plat No.	Yield in bushels of dry ear corn per acre
Clarage	1	113.7	Clarage x Longfellow	20	75.4
	4	95.8		23	69.8
	7	101.3		26	64.1
	10	94.4		29	72.0
	13	84.8		32	79.3
	16	97.6	Longfellow	3	23.3
	19	87.1		6	29.9
	22	75.6		9	30.5
	25	74.1		12	33.9
	28	70.6		15	37.1
	31	74.8		18	40.1
Clarage x Longfellow				21	28.3
	2	88.0		24	35.1
	5	85.2		27	23.1
	8	93.3		30	28.9
	11	74.6		33	35.3
	14	82.1			
	17	90.5			

The mean difference in yield between Clarage and Clarage x Longfellow was found to be 8.67 bushels in favor of Clarage, and the standard deviation of the differences was found to be 8.263, thus giving a Z value of 1.049. The odds are 163 to 1 that this value is significant. (According to Fisher's table of t, the P value is less than 0.01.)

The mean difference in yields between Longfellow and Clarage x Longfellow was found to be 48.07 bushels in favor of the first generation cross and the standard deviation of the differences was found to be 8.989, hence there can be no question but that there is a real difference.

The comparative trial mentioned above was carried out on the agronomy farm at an altitude of about 1,200 feet, whereas the earlier trials were conducted at altitudes of over 2,000 feet. Consequently, it seemed advisable to repeat the 1929 test at a higher altitude. In 1930, seed from the same source as that used in 1929 was planted in alternate single-row plats on the farm (altitude about 2,000 feet)

of G. W. Daniels in Randolph County. Six seeds were planted in hills 3½ feet apart. Later the stand was thinned to three stalks per hill. The yields calculated on a water-free basis were determined from 25 hills harvested from each plat. Five plats of Clarage and five of Clarage x Longfellow were grown. The yields in pounds per plat are shown in Table 3.

TABLE 3.—*Yield of a first generation cross, Clarage x Longfellow, and the higher yielding parent, Clarage, grown in Randolph County in 1930.*

Yield in pounds per plat of moisture-free ear corn		Difference
Clarage	Clarage x Longfellow	
13.8	13.2	+0.6
16.3	14.4	+1.9
17.0	16.5	+0.5
15.3	18.6	—3.3
20.3	15.2	+5.1

The data obtained in 1930 corroborate those obtained in 1929 in showing that the yielding ability of the first generation cross does not exceed that of the higher-yielding parent after the latter is subjected to an ear-to-row selection. In four of the five paired plats, Clarage gave the greater yield. Student's method of analysis does not show a significant difference.

The growing season of 1930 was abnormally dry and therefore probably favored the first generation cross since it normally matures about 10 days earlier than Clarage, the later parent.

DISCUSSION

It was pointed out above that yield of the F_1 varietal cross, Clarage x Longfellow, exceeded the average yield of the higher-yielding parent in all but one of nine tests carried on during three years in three counties of the state. These results seemed to indicate that the first generation cross possessed yielding ability superior to that of either of the parents.

When these same varieties of corn were first subjected to an ear-to-row test to discover the higher-yielding ears, and when crossed seed obtained from these higher-yielding ears was used in further tests, the results were quite different. Instead of the first generation cross yielding more it actually yielded less than Clarage, the higher-yielding parent, during one year, and certainly did not yield more than Clarage during the second year. These results seem to indicate that the single mass selection by the ear-to-row method was as effective in discovering combinations of genetic factors favorable to yield in the Clarage variety as was hybridization between Clarage and Longfellow in bringing together favorable combinations.

Experimental evidence indicates that continuous ear-to-row breeding does not lead to a progressive increase in yield. It is possible that this method reaches its maximum effectiveness the first year it is practiced through the selection of individuals having a maximum number of different factors favorable to yield.

If superior yielding ability in corn is the result of a great number of favorable growth factors as has been suggested, and further, if the growth factors found in any one variety of corn are common to the other varieties, there is no theoretical reason why one should expect a first generation cross between varieties to give a yield superior to that of either of these varieties, provided they first had been subjected to rigorous selection for high yield. On the other hand, if there are different kinds of growth factors which produce high yield in the two varieties, it is conceivable that a first generation cross between them might excel either in respect to this character.

SUMMARY

In some earlier work with first generation crosses in corn, Clarage x Longfellow gave higher yields than either of the parent varieties. When these same two varieties were subjected to an ear-to-row test to discover the higher-yielding ears and when a cross was made between them, no increase in yield of the F_1 generation over the higher-yielding parent was obtained.

PREPOTENCY OF INBRED SIRES ON COMMERCIAL VARIETIES OF MAIZE[1]

E. W. LINDSTROM[2]

Between the present standard corn breeding method of mass selection and the contemplated perfection of the newer breeding methods involving the utilization of hybrids from inbred strains, there still exists a gulf. This is due not only to the natural conservatism of the practical breeder towards new ideas, but also to the fact that much experimentation is still necessary before the use of hybrids will have become thoroughly established and adapted to large areas. During the interim any simple and successful system of corn breeding that will gradually introduce the newer concepts to the practical breeder should have abundant justification. Herein is reported a possible method that would seem to be eminently useful under these circumstances.

While experimenting with a practical method of line-breeding in corn, the writer had occasion to pollinate commercial corn with some of his inbred strains (inbred for six generations). He was at once struck with the surprising prepotency of some of these inbred lines, particularly in the matter of plant uniformity, ear type, ear height, disease resistance, lodging, and yield. It was especially noted that such inbred-sire crosses or "top-crossed" progenies possessed a much lower percentage of poor or barren stalks than was true in commercial varieties.

If a second dose of the same inbred sire was used on these progenies there was a quick return to the poorer vigor of that inbred strain. In other words, a single dose of certain inbred sires on a commercial variety proved to be optimum for practical purposes.

Much the same general experience has been afforded in observing progenies of hybrids or single crosses from inbred strains when back-crossed to one of the parental inbreds. A marked return to the type of that inbred parent is plainly evident. Furthermore, the same F_1 hybrid when crossed with a third unrelated inbred ordinarily produces a progeny that is surprisingly uniform in view of the heterozygosity of one of its parents, the F_1 hybrid. In general, much the same uniformity is present in double crosses involving four different

[1]Paper No. 37, Department of Genetics, Iowa State College, Ames, Iowa. Presented before the geneticists interested in agriculture and the joint genetics section of the A. A. A. S. at Cleveland, Ohio, December 29, 1930. Received for publication February 2, 1931.

[2]Chief in Genetics.

inbred lines in which both immediate parents were highly heterozygous. All these experiences drove home the impression that uniformity and good yield might well be obtained by the use of an inbred line even on such variable stock as the average heterozygous commercial variety.

Accordingly, series of tests were inaugurated with dent corn and later with sweet corn with the expectation of determining the relative prepotency of inbred lines from the practical standpoint.

FIELD CORN EXPERIMENTS

The experiments with yellow dent corn were commenced with the Krug variety as the mother, since this variety had been consistently one of the highest yielders in the Iowa yield test in which the best varieties compete yearly. It was felt that unless some improvement could be made over the best commercial variety, any new method of corn breeding would be impracticable. Seed of the Krug variety was purchased in sufficient quantity so that the original seed could be used as a check during the experiment.

This Krug variety was hand-pollinated with some of the best inbred lines. Because of limited facilities only five to six ears from each inbred-sire cross were ordinarily used. The progenies from such top-crosses were compared for yield, lodging, smut infection, plant height, and ear height, both in the genetics breeding plats and to a limited extent in the regular Iowa yield test. There was no selection of plants to be pollinated in the Krug variety. Assistants merely bagged a large number of ears as they developed, and later these were fertilized at random with pollen from the inbred lines, most of which had been inbred five or more generations. Only those sires which had done well in hybrid combinations were used.

The yield tests in the genetics plats were based on four or more replications of plats of two 10-hill rows (usually three plants to the hill). During the first year each top-crossed Krug ear was used in a single plat. Later, the seeds of five to six ears from a single sire were combined. The individual plats were harvested in sacks and dried to approximately 15% moisture. The plats in the Iowa yield test were two 12-hill rows and were replicated 10 times.

The experimental results obtained in the genetics field plats for the seasons of 1929 and 1930 are arranged in Table 1 in which is shown the comparisons in yield between the original mother variety (Krug) and the top-crosses with various inbred sires. In 1929, five sires were tested of which two (LAN and PRO) produced significant increases in yield over Krug.

In 1930, a very dry season, most of the inbred-sire crosses showed highly significant increases in yield. Some of this increase may be due to the fact that the Krug variety when grown in the vicinity of Ames is inclined to be a trifle late. The inbred-sire crosses were all slightly earlier. Because of the very critical drouth of 1930, when no rain fell between July 4 and the middle of September, there occurred much tassel-firing, and as a result pollination of the later varieties may have been restricted. This factor, however, was not serious enough to be noticeable by inspection of the ears, and is not thought to be the real cause of such great differences in yield as occurred in 1930.

TABLE 1.—*Yield test, genetics plats, field corn in bushels ear corn per acre at 15% moisture.**

Crosses	1929			1930		
	Yield	Increase %	Number replications	Yield	Increase %	Number replications
Krug, check	83.1	—		39.2	—	15
Krug x inbred sire LAN	96.0	15	9	44.0	12	6
Krug x inbred sire PRO	94.7	14	5	—	—	-
Krug x inbred sire WAL	88.6	7	6	45.3	16	6
Krug x inbred sire OSE	86.0	5	5	43.3	10	4
Krug x inbred sire LAS	83.1	0	6	—	—	-
Krug x inbred sire BLS	—	—	-	56.9	45	4
Krug x inbred sire BLX	—	—	-	51.7	32	4
Krug x inbred sire MCC	—	—	-	47.2	20	6
Krug x inbred sire CLA	—	—	-	44.9	15	8

*Replications based on plats of two 10-hill rows, totalling 20 hills with three plants to the hill.

While the increases in yield of some of the inbred-sire crosses are rather surprising, the uniformity of the plants was especially striking. Furthermore, the inbred sires were very noticeably prepotent in fixing ear type (Fig. 1). The LAN inbred sired a progeny with characteristically long, medium-slender ears with 12 to 14 rows and kernels uniformly shallow-dented. The OSE sire produced a more cylindrical ear with rougher-dented kernels. In all the top-crosses the kernel type was much more uniform than that in the Krug variety. The effect of the inbred sires was particularly evident in decreasing the percentage of barren stalks, the records showing that the top-crosses invariably had more marketable ears to the row.

In the matter of resistance to smut and lodging, some extremely suggestive results were encountered. Readings were taken on relative smut infection (scale of 1 to 5, the latter representing the

greatest infection) and also on amount of lodging (scale of 1 to 5, the latter representing all plants down). The results in 1929 and 1930 are recorded in Table 2.

TABLE 2.—*Comparison of smut infection and lodging in field corn.*

Crosses	Smut infection grades		Lodging grades	
	1929	1930	1929	1930
Krug, check	3.8	2.3	2.5	2.6
Krug x inbred sire LAN	1.5	1.3	1.6	2.3
Krug x inbred sire PRO	2.3	—	1.8	—
Krug x inbred sire WAL	1.3	1.8	1.4	2.7
Krug x inbred sire OSE	1.8	3.3	1.2	1.7
Krug x inbred sire LAS	1.5	—	3.2	—
Krug x inbred sire BLS	—	1.5	—	2.5
Krug x inbred sire BLX	—	1.5	—	3.0
Krug x inbred sire MCC	—	2.0	—	2.0
Krug x inbred sire CLA	—	2.1	—	1.5

Most of the inbred-sire crosses showed less smut infection than did Krug. This is probably due to the fact that the inbred sires had

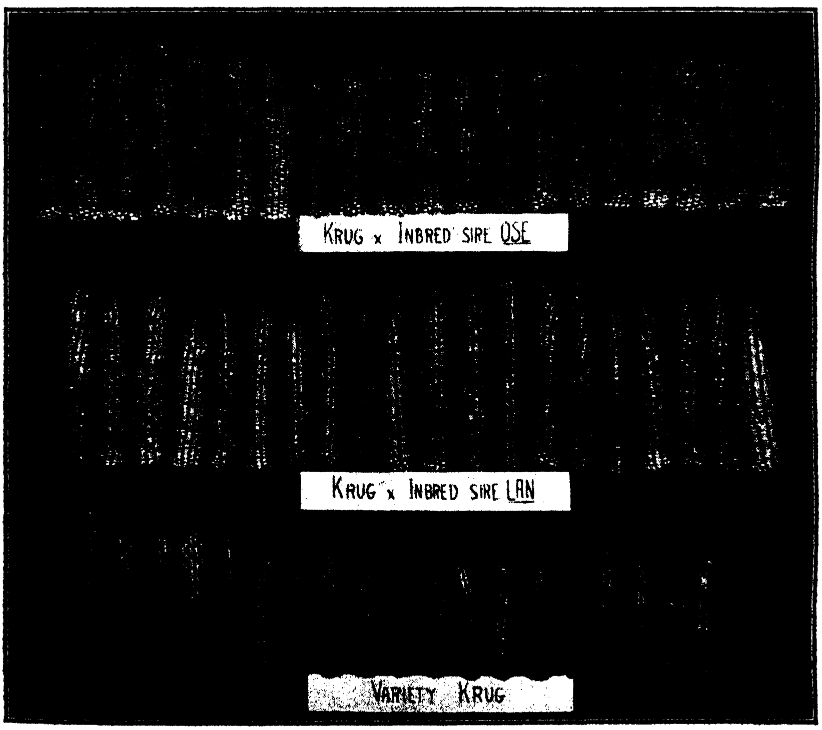

FIG. 1.—Comparison of ear type in "top-crosses" of a commercial variety of field corn with inbred sires LAN and OSE.

been previously selected for smut resistance. Apparently, resistance to smut is dominant to some degree.

In the matter of lodging more than half of the inbred-sire crosses were superior to the Krug mother variety. If an inbred sire is prepotent in this respect, this "top-cross" method affords a practical means of improving the stiffness of stalk of commercial varieties of corn, a factor that is becoming increasingly important with the advent of machine harvesting.

TABLE 3.—*Data from Iowa corn yield test, showing bushels of shelled corn per acre at 15% moisture.**

Crosses	1928	1929		
	District No. 4	District No. 7	District No. 8	District No. 9
Krug	—	63.5	72.6	—
Ave. variety entries	70.2	58.2	75.6	88.2
Ave. hybrid entries	76.6	64.8	84.2	99.6
Krug x inbred sire LAN	79.1	71.3	94.0	105.2
Krug x inbred sire LDG	77.1	—	—	—
Krug x inbred sire CLA	69.8	—	—	—
Krug x inbred sire LON	—	—	89.5	—
Krug x inbred sire WAL	—	—	82.8	—
Krug x inbred sire PRO	—	—	81.8	—

*Yields based on 10 replications of plats with two 12-hill rows.

Yield comparisons were also obtained by entering the inbred-sire crosses in the Iowa yield test. The data appear in Table 3 for the seasons of 1928 and 1929. In 1928, the top-crosses were entered in district No. 4 (western, northcentral Iowa) where no Krug was entered. The cross, Krug x Inbred LAN, showed up fairly well, being better than the average of the "hybrid" class which comprised a large number of excellent entries. It was distinctly superior to the average of the standard varieties.

A better comparison is afforded in 1929 when the original Krug seed was also entered (district No. 8, vicinity of Ames). In this year all the inbred-sire crosses proved to be significantly better than the mother variety. The cross Krug x Inbred LAN also competed as a section entry (in three districts across the state) and was only 1.1 bushels less in yield than the best hybrid (a double cross of inbreds). Apparently, the LAN (from Lancaster variety) inbred "nicks" particularly well with Krug under most conditions, and it has been consistently better than this variety in all tests made thus far.

The standard deviation of a mean difference is given as 4.6% in district No. 8. This would make any yield difference of 10% or

more statistically significant. All the inbred-sire crosses in district No. 8 are 13% or more better in yield than the mother variety.

It must be recognized that one of the limitations of this experiment is the fact that only five to six ears of the mother variety were devoted to any one sire in any one season. While there was no conscious selection of the mother plants, it is obvious that only normal plants were chosen. In this sense the samples may not have been truly representative of the mother variety, although this is not thought to be a really serious factor. The fact that similar and consistent results were obtained in different years from the same top-cross would seem to afford reasonable evidence of the generality of the results. Nevertheless, the experiments must and will be tested in detasseling plats where all of the normal ears of the mother variety will be used for seed stock.

SWEET CORN EXPERIMENTS

Because uniformity of maturity of ears is so important in sweet corn used for canning purposes, it was felt that this top-cross method would be particularly valuable. Accordingly, a strain of Evergreen sweet corn was top-crossed with 10 of the best inbred strains of sweet corn (from Evergreen varieties) which had been self-pollinated for five years.

Yield data from this series of inbred-sire crosses (composite of five to six ears from each top-cross) were obtained in 1930 by harvesting the mature ears from replications of two 10-hill rows. For this preliminary work, the canning or roasting-ear stage was not used as information on the seed ear was most desired. The data from 10 inbred-sire crosses appear in Table 4, together with those from the check which was the original Evergreen variety.

In every case, the inbred sires increased the yield to a surprisingly high degree, particularly in the case of sires 818, 848, 857, 827, and 836. The same uniformity that was found with the field corn occurred here (Fig. 2). The prepotency of some of the inbred sires for ear type was remarkable as may be noted in the illustration. Inbred 818 sired a fine, straight-rowed, large ear with excellent and uniformly-shaped kernels. Sire 836 impressed a uniformly short ear type upon the progeny. These ears were noticeably heavy for their size. It was again noted that the inbred sires caused an ear to develop on practically every plant in the top-cross progenies.

The greater increases in yield in case of sweet corn over those found with field corn probably can be explained by the fact that the mother variety, Evergreen, was just an average selection com-

prising the usual 8 or 10% of barren stalks or those producing only nubbins. In the case of the field corn test, the mother variety was one of the best, if not the best, selection in this area.

TABLE 4.—*Sweet corn yield test, genetics plats, 1930, bushels ear corn per acre at 15% moisture.**

Crosses	Yield	Increase %	Smut grade	Lodging grade
Evergreen, check	23.4	—	2.2	2.1
Evergreen x inbred sire 818	36.0	54	1.4	3.1
Evergreen x inbred sire 848	34.7	48	1.7	2.5
Evergreen x inbred sire 857	34.0	45	1.0	2.2
Evergreen x inbred sire 827	33.1	41	1.7	3.3
Evergreen x inbred sire 836	32.4	38	2.3	2.2
Evergreen x inbred sire 853	28.6	22	1.8	1.7
Evergreen x inbred sire 880	27.9	19	2.0	2.0
Evergreen x inbred sire 855	27.6	18	1.1	2.8
Evergreen x inbred sire 892	27.6	18	1.1	2.0
Evergreen x inbred sire 883	26.0	11	1.7	1.7

*Yields based on six replications of plats with two 10-hill rows, except check which had 20 replications.

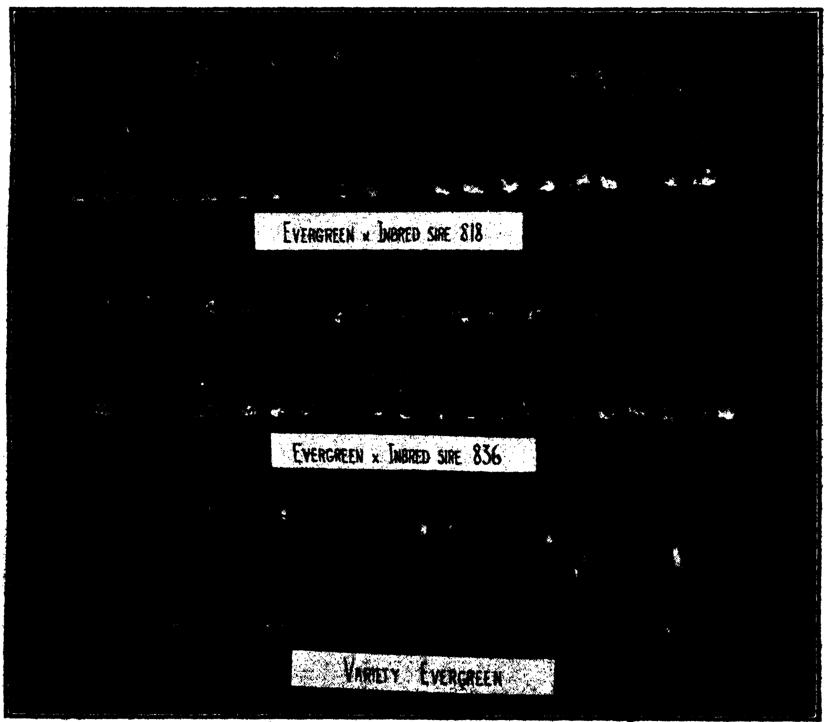

FIG. 2.—Comparison of ear type in "top-crosses" of a commercial variety of sweet corn with inbred sires 818 and 836.

Throughout the season observations were made on uniformity of maturity of the ears. As far as could be determined by the outward appearances of the plant and the husks, the inbred-sire crosses were conspicuously more uniform in ripening than the Evergreen variety.

DISCUSSION

The object of this report is to present in a preliminary manner the results of an experiment with the prepotency of inbred sires on commercial varieties of corn that has revealed a surprisingly simple method of improving the yield and quality. Naturally, verification with other varieties is necessary, and it is hoped that corn breeders will take advantage of its simplicity and test the method on a large scale. The practical technic is almost obvious, and yet experimental details of several sorts need to be taken into consideration.

For practical usage in the production of seed corn, by the use of inbred sires on commercial varieties, it is necessary to have an isolated plat where the mother variety may be planted with the inbred sire (the latter in every third or fourth row). The rows with the mother variety are to be detasseled. Commercial seed is harvested only from these rows. This permits the breeder or seedsman to use or sell seed which is acceptable to the growers.

If the detasseling plat has been properly isolated and handled, the continuation of the inbred sire is rendered automatic, and no extra work need be done in this respect. Compared with the difficulties encountered in the use of double crosses where four inbred lines must be maintained and two years of detasseling are necessary, the method is refreshingly simple and direct. It can be entrusted to the average progressive breeder and does not necessarily require the services of a specialist.

There are two chief difficulties that must be mastered. First, the most desirable inbred sire for any standard variety must be discovered by experiment. Not all inbreds "nick" equally well; nor can the prepotency of an inbred be determined by its appearance. Moreover each variety can be corrected in some of its most obvious deficiencies by the use of appropriate sires. This is particularly true of lodging, disease susceptibility, and maturity. The remarkable prepotency of certain inbred lines of field corn in hybrid combinations has recently been reported by Jenkins.[3] From a large series of experiments he has presented critical data on yield, lodging, time of tasseling and silking, plant height, percentage of moldy ears, ear

[3]JENKINS, M. T. Correlation studies with inbred and crossbred strains of maize. Jour. Agr. Res., 39: 677–721. 1929.

shape, and row number, showing that different inbred parents are strikingly prepotent in such characters. Some inbred lines produced high-yielding crosses in practically all combinations.

Second, for efficient pollination, considerable care or experience is necessary in the choice of the inbred sire. It should be producing abundant pollen at the time the silks of the mother variety are exposed. Also, an inbred sire that is too short in stature may be at a disadvantage as a pollinating parent.

In the case of sweet corn, where many of the inbreds are suckered, the question of good pollination is not so dangerous. However, in this case, some care must be exercised in the choice of the inbred sire because some suckered inbreds may produce objectionable suckering in the progeny. Actually this has not been observed as yet in these sweet corn experiments, although it has occurred in single crosses of field corn involving inbreds that were markedly suckered.

While the experiments with the use of inbred sires on commercial varieties of field and sweet corn have given rather surprisingly good results, it must be realized that this method of corn breeding is not expected to be superior to the best double cross combinations that have been perfected and adapted to local conditions. The obvious virtues of the method are its simplicity and its practicability for the private plant breeder or seedsman who is not yet ready to grapple with the complex problems of hybrids from inbred strains.

In these experiments the inbred line has only been used as a sire on a commercial variety. It is of course possible to use it as the dam in which case no isolated breeding plat is necessary because the inbred may be planted in the regular corn field and detasseled. This advantage, however, is more than offset by the fact that the seed gathered for next year's crop is poor in quality and small in quantity. Moreover, the inbred dam in this case is lost and must be acquired anew in some manner. When used as a sire, the inbred line is continued automatically if the detasseling in the isolated breeding plat has been thoroughly done.

It would seem highly probable that our simple top-cross system of breeding will prove to be admirably suited to modern animal breeding. Because of the fundamental difficulty of obtaining many good inbred strains of animals, even in poultry and swine, the use of double crosses seems entirely out of the question for the immediate future. Moreover, the use of single crosses is also impracticable in animals because of the relatively poor vigor or productivity of the inbred dam. Accordingly, the use of inbred sires on standard breeds would seem to afford the best solution for the progressive breeder.

Before embarking on a program of this sort with animals, however, considerably more verification of the inbred-sire cross or "top-cross" system of breeding is necessary. One of the objects of this report is to stimulate further research on the problem, research that will extend the results to many standard varieties of plants and breeds of animals.

In conclusion, it should be pointed out that the inbred-sire cross as a method of practical corn breeding is still in its pioneer stages. Its greatest limitation is the lack of an outstandingly good inbred line. Practically all inbred lines are noticeably deficient in several respects. There seems to be no reason why better strains cannot be developed. When a reasonably high-yielding, stiff-stalked, disease-resistant strain that produces abundant pollen is once isolated, one may confidently expect "top-crossed" progenies immeasurably superior to any now in existence. Given a sire like this, the more complicated systems of breeding may become unnecessary for the average grower or breeder of corn.

SUMMARY

Experimental results with the use of inbred sires on commercial varieties of dent and sweet corn have demonstrated that significantly increased yields of grain are possible. A marked prepotency of the inbred sires for ear type, disease resistance (smut), lodging, and uniformity of maturity was definitely established.

The simplicity of the practical phases in the production of seed renders this inbred-sire breeding system practicable for the average progressive corn breeder. Its application to modern animal breeding is extremely suggestive.

AN INDICATION THAT CORN TILLERS MAY NOURISH THE MAIN STALK UNDER SOME CONDITIONS[1]

GEORGE H. DUNGAN[2]

The value of tillers on corn plants has been questioned by corn growers for many years. The early assumption was, and the general belief now is, that tillers are parasitic on the stalk from which they arise and, therefore, are detrimental to yield. In small grains a large proportion of the tillers produce grain and free tillering is looked upon with favor. In corn such a small proportion of tillers produce grain and those that do frequently bear such small, late-maturing ears that tillering is considered undesirable. So widespread is this attitude toward these structures on corn that the popular name "suckers" is used with the feeling that the term is appropriate.

A number of field experiments have been conducted to test the profitableness of removing tillers from corn. These for the most part show not only no increased yields for tiller removal, but often an actual reduction in quantity of grain produced. For instance, Lyon (4),[3] from tests conducted during two years, found that removal of tillers reduced the average yield of field corn 17 bushels per acre. Ricks (8) decreased yields of corn by "suckering" 8.3 bushels per acre in 1910, and 2.0 bushels in 1912. Williams (13) and Williams and Etheridge (14) obtained slightly reduced yields of grain by tiller removal.

Montgomery (6) in tests covering a three-year period (1906–1908) found that the injury caused by the removal of tillers varied with the number of stalks in the hill. Tillers pulled from one-stalk hills reduced the average yield 14.0 bushels per acre; from two-stalk hills, 9.7 bushels; from three-stalk hills, 5.2 bushels; from four-stalk hills, 1.8 bushels; and from five-stalk hills, 4.1 bushels. McClelland (5) found that removing suckers produced no detrimental results when yields were below 35 bushels per acre, but when yields were above 45 bushels removal reduced the yields.

A number of similar tests have also been made with sweet corn. DeBaun (1) found that non-suckered sweet corn gave the heaviest yield, and that the yield was reduced in proportion to the lateness of suckering. He did find, however, when the tillers were removed early in the growth of the plants, that the ears were ready for market

[1]Contribution from Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication February 25, 1931.

[2]Associate Chief in Crop Production.

[3]Reference by number is to "Literature Cited," p. 669.

two to four days earlier than where they were removed late or not at all. Hepler (3) reported that with Early Crosby sweet corn the plants with tillers left on produced 5.8% larger yield than the suckered rows, but with Golden Bantam there was a 2.6% decrease due to leaving the tillers on. Recently, Thompson (10) and Thompson, Mills, and Wessels (11) presented results which showed a decrease in yield of marketable ears when tillers were removed, although the decrease was not statistically significant, except in the case of late tiller removal.

Thus the literature rather consistently points to the general conclusion that tiller removal is actually detrimental to grain production. This raises the question as to the function of tillers.

Is the decrease in grain yield due primarily to the wound and root disturbance occasioned by jerking off the tiller? Or, is the tiller itself an actual contributor to grain formation? The tiller may produce an ear, or it may supply the ear-bearing stalk with grain-forming materials. It is with the latter phase of tiller functioning that this paper deals.

EXPERIMENTAL RESULTS

TILLER REMOVAL

In order to avoid at least a part of the injury sustained when the usual field method of pulling suckers is practiced, the tillers were cut off with a knife at the surface of the soil. Two tiller-bearing plants having the same general vigor and growing in adjoining single-stalk hills were selected. From one, the tiller was removed on August 9 when the grain of the ears was in the early milk stage. The tiller on the other plant was not disturbed. Fourteen such pairs of plants were chosen and prepared in the same manner. At harvest time the ears from each plant were harvested and tagged separately. The average yield and average test weight of the grain are presented in Table 1.

The removal of the tillers was accompanied by a reduction in grain yield of 35.9 grams, or 15%. There were 10 instances out of the 14 comparisons in which the grain yield showed a decrease for cutting away the tillers. In four cases, the yields from tiller-cut plants were higher than the check plants. So, even though the average difference in yield was as high as 15%, the significance of this result as indicated by odds calculated by Student's method is not great. As regards test weight, the tiller-bearing plants showed a superiority of 2.7 pounds with odds of 27:1, which approaches the 30:1 ratio of odds that is accepted by some as indicating significance.

TABLE 1.—*Yield and test weight of dry shelled corn produced by tiller-bearing plants compared with plants from which the tillers had been removed.*

	Number of comparisons	With tillers	Without tillers	Difference in favor of plants with tillers	Odds
Yield, grams	14	238.7	202.8	35.9	11:1
Test weight, pounds	14	60.5	57.8	2.7	27:1

TILLERED AND NON-TILLERED PLANTS COMPARED

In an attempt to learn whether tiller-bearing plants are higher yielding than non-tiller-bearing plants, two stalks of the same general vigor and stage of growth were selected from adjoining hills—one stalk with a tiller and one without. No treatment was given the plants. The two that appeared to be equal in every respect except in the matter of possessing a tiller were recorded as a pair in making this comparison. The tillers were from one-half to three-fourths the height of the main stalk. These plants were chosen on August 9 when the grain was in the early milk stage. Twenty-one pairs were selected. A summary of the yield data is shown in Table 2.

TABLE 2.—*Yield and test weight of dry shelled corn produced by tiller-bearing plants compared with non-tiller-bearing plants growing in adjoining hills.*

	Number of comparisons	With tillers	Without tillers	Difference in favor of plants with tillers	Odds
Yield, grams	21	242.70	239.70	3.00	2:1
Test weight, pounds	21	59.53	59.51	0.02	None

The average yielding superiority of tiller-bearing plants was only 3.0 grams with odds of 2:1 which are too low to be considered significant. In the 21 comparisons there were 10 instances in which the tillered plants exceeded the non-tillered plants in yield, 10 instances in which the reverse was true, and 1 instance in which the two yielded the same. The test weight of the two was practically the same, there being a difference of only 0.02 pound in favor of the plants with tillers. This preliminary test indicates that tiller-bearing plants under ordinary conditions may not be any higher yielding than non-tiller-bearing plants. Such a test should, however, be conducted over a period of years before a satisfactory conclusion can be reached.

Wiancko (12) found that the average yield of the rows having the highest percentage of tillers was higher than the average of the rows having the lowest percentage of tillers. His results strengthen

the view of those who hold that a tendency to produce tillers indicates extra vigor in the plant. Further experimental data are needed, however, to decide whether corn plants tiller because of extra vigor, as suggested by Sherwin (9), or are extra vigorous because of tillers. The work of Halsted (2) suggests that extra vigor may be the cause of tillering, since in his experiments, the large-grained corn produced a greater percentage of tillers than small-grained corn. He also found that shallow planting resulted in more suckers than deep planting.

TILLERS NOURISH THE MAIN STALK

From unpublished results of studies at the Illinois Experiment Station on the influence of blade removal, it has been concluded that complete defoliation of the corn plant results in almost complete cessation of plant and ear development. It was decided from this that the defoliation of the main stalk of a tiller-bearing plant might be a suitable method of demonstrating whether the tiller contributes to the development of the main stalk and its ear. Accordingly, on August 15 when the grain was in the milk stage, one plant of each of 20 pairs of plants was selected for treatment. One of each pair was without a tiller and one possessed a tiller. All of the blades were removed from the non-sucker-bearing plants and from the main stalk of the sucker-bearing plants by clipping with hand shears. The blades on the tillers were unmolested.

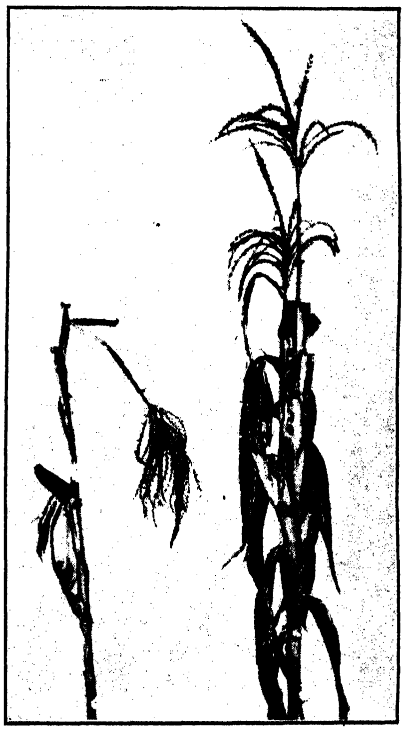

FIG. 1.—Plant on the left and the main stalk of the plant on the right were defoliated on August 15. The photograph taken Sept. 16 shows the contrast between these plants brought about by the fully-leafed tiller of the plant on the right.

On September 16, every one of the ear-shanks on the plants without suckers was broken, and not one was broken on the plants with suckers. Many of the suckerless defoliated plants were broken below the tassel and all were brown and apparently

dead. All the plants bearing suckers were unbroken and alive. A representative hill of each is illustrated in Fig. 1. A summary of the harvest data is set forth in Table 3.

TABLE 3.—*Percentage increase in yield of defoliated plants bearing tillers compared with similar defoliated plants without tillers.*

Yield factor	Number of comparisons	Percentage superiority	Odds
Yield of shelled corn	20	92.08	>9999:1
Weight of 100 kernels	20	87.70	>9999:1
Test weight of shelled corn	19	14.60	>9999:1
Weight of cob	20	33.99	3332:1
Diameter of ear	20	7.89	832:1
Length of ear	20	11.78	168:1
Weight of ear bearing stalk	19	21.82	57:1

The superiority of the tiller-bearing plants is clearly shown by their greater yield. The odds are high enough to indicate statistical significance in every case. The data are markedly consistent in favor of the tiller-bearing stalk. Even with the weight of ear-bearing stalk which has the lowest odds, 57:1, there were only 5 of the 19 comparisons which showed the suckerless stalk weighing more than the one with a sucker attached.

The grain was benefited more than the stalk and cob by the supporting tillers. Fig. 2 shows representative pairs of ears from this test. Since the kernels are later in development than any other part of the corn plant, they would be relatively immature when defoliation was administered. The tiller attached to the main stalk has supplied the grain-forming materials and has almost doubled the size of the individual grains, as well as the yield of shelled corn.

Similar defoliation tests made earlier (July 25) when the ear shoots were just appearing gave different results. The removal of all blades from plants that did not have suckers resulted in complete barrenness in every case. Similar treatment of plants bearing suckers resulted in the formation and maturity of ears on 6 out of 10 plants. Four of these ears were produced on suckers and two on bladeless main stalks with one sucker each attached.

The removal of the four middle blades from sucker-bearing and non-sucker-bearing plants in the "tassel and shoot emerging" stage resulted in no appreciable difference in yield of grain, weight of stalk, size of kernels, and test weight per bushel.

When the main stalk was removed and the sucker allowed to develop, the sucker rapidly increased in size and at the end of the growing season possessed the proportions and general appearance of a main stalk. The air-dry weight of such suckers was 31.4% greater than that of suckers attached to the main plant. In some cases, these suckers produced ears.

DISCUSSION

It is not the purpose of this presentation to set forth the theory that tillers in corn are always contributors to yields by supplying the

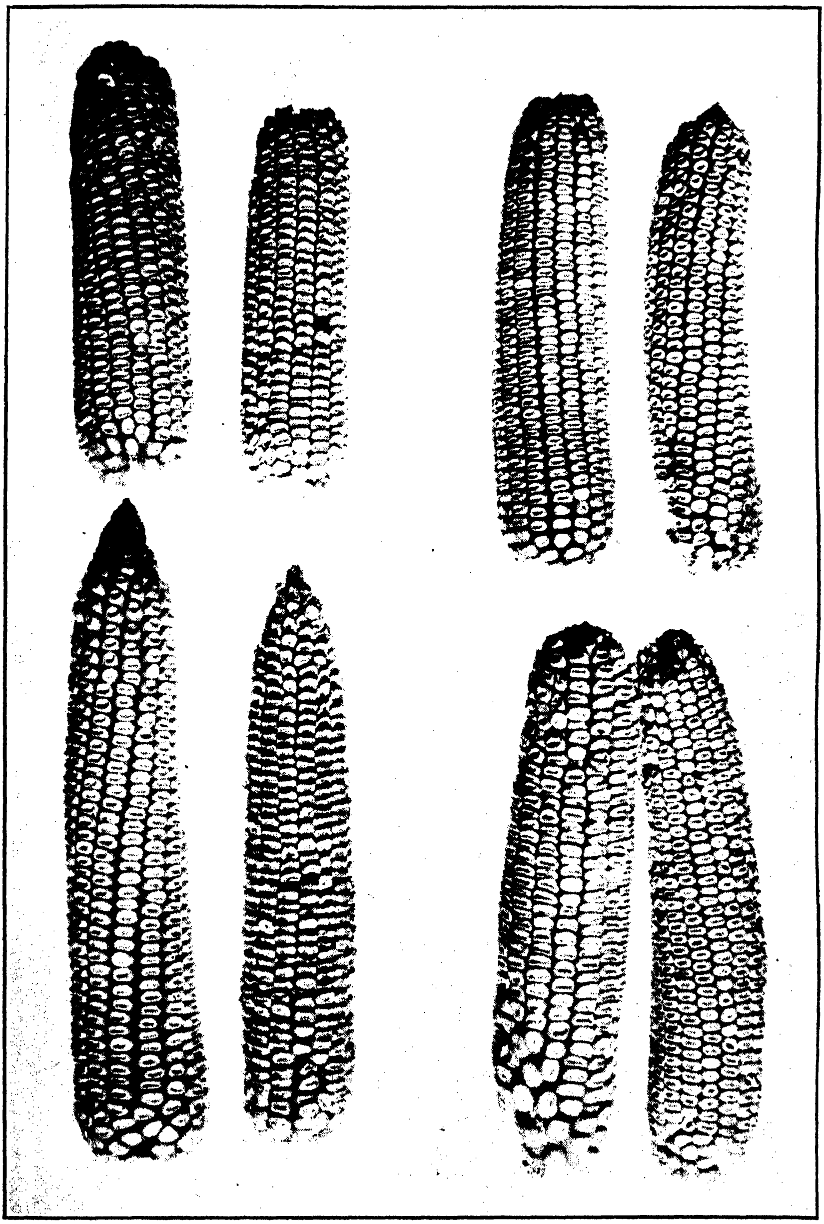

FIG. 2.—The ear at the left of each pair was produced on a defoliated stalk bearing a fully-leafed tiller. Ears at the right grew on defoliated stalks without tillers.

main stalk with grain-forming materials. Obviously, tillers are injurious under some conditions. For instance, during the season of 1930 when all corn tillered excessively, the fields that were the more fertile from the standpoint of nitrates suckered much more than less fertile fields. Ordinarily, the more fertile fields produce the larger yields of corn, but such was not the case during this season. The excessive tillering on these fertile fields resulted in the early production of so many stalks that the moisture supply later in the season was not adequate and all stalks, including the main stalk, suffered. True, a number of the later formed tillers died as the drought became more severe, and probably much of the plant food material was transferred to the main stalk before the suckers collapsed, yet the energy and moisture loss involved in the production of these "fired" suckers must have been considerable.

FIG. 3.—A section through a main stalk and its tiller showing the vascular connection between them.

Rodrigues (7) has shown in sugar cane that the stalks developed from the original transplanted sprouts were richer in sugar than the suckers. With few exceptions, he found a gradual diminution of sugar content and weight of stalk from original plants to the youngest sucker. This has led to the suggestion to sugar cane growers that early suckering be encouraged and late suckering be repressed. It would seem reasonable that the late suckers of corn would be of less value than early formed ones. Unlike cane, however, the main stalk of corn builds its reserves into an ear. There may be, therefore, a period during ear formation when the sugars,

proteins, etc., in the main stalk are exhausted to a point below the concentration of these materials in the sucker. Under such conditions, it is reasonable to believe that the tiller, having vascular connection with the main stalk as it does, would nourish the main stalk.

Lyon (4) stated that young tillers are at first attached to the main plant and draw their nourishment from it, but they soon develop their own roots and finally become virtually independent plants. He reported, further, that sometimes entire separation takes place through the pushing away of the tiller by the rapid growth of both itself and the main plant. This is distinctly different from the writer's observations. In making a number of examinations, entire separation has never been observed. Most of the connections appear as shown in Fig. 3. Sometimes the connection is slight and requires great care in trimming away the roots in order to see it. The higher yields of the sucker-bearing defoliated plants compared to similarly treated suckerless plants are conclusive evidence that there is a functioning vascular connection between the sucker and the main stalk.

SUMMARY

Removing tillers from corn plants in the early milk stage caused a slight reduction in yield and test weight of grain, although the differences were not statistically significant.

Comparison of the yield and test weight of grain from individual plants with suckers and those without suckers showed a very slight superiority for the plants with suckers, but here again no significance can be attached to the small differences observed.

Defoliation of plants with and without suckers when the grain was in the early milk stage resulted in striking superiority of the plants with suckers in yield of grain, test weight per bushel, weight of 100 grains, diameter of ear, length of ear, and weight of ear-bearing stalk. The differences were statistically significant in every case.

A similar defoliation test made when the ear shoots were just emerging resulted in no further growth of the main stalk, but a more rapid, main stalk-like growth of the sucker.

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THE SHEDDING OF NODULES BY BEANS[1]

J. K. WILSON[2]

Under uniform conditions nodules on leguminous plants probably remain as long as they are of any service to the plant. If growth conditions can accommodate a greater number, new nodules may develop. If adverse growth conditions are encountered after a period of favorable growth, nodules may be shed. Experiments have shown that with an increase in moisture there is an accompanying increase in nodulation until the plant has reached an equilibrium at this new moisture content with those symbiotic conditions that bring about nodulation. Little is known, however, about what happens to a portion or all of the nodules that have developed under the best nodulating conditions when the plant encounters less favorable growth circumstances. It would seem logical that if an increase in moisture causes a plant to develop more nodules that the reverse condition should cause it to shed nodules. The observations recorded in this paper are of interest in this connection.

[1]Contribution from the Dept. of Agronomy, Cornell University, Ithaca, N. Y. Received for publication February 18, 1931.

[2]Professor of Soil Technology.

TECHNIC

The effect of a reduction in moisture content from that which was present when nodulation occurred was measured by observing the number and physical condition of nodules that remained on plants after they were subjected to various degrees of desiccation. The exact procedure of how such information was obtained is given in the following paragraphs.

Dunkirk silty clay loam was taken from a field where beans were growing. This was placed on a large canvas and uniformly mixed. Equal weights of the moist soil were put in one-half gallon crocks. The total weight was taken of each crock with the soil in it in order that moisture conditions could be controlled. A sample was also used for moisture determination. Calculations showed there were in each crock 1,860 grams of dry soil. With these facts at hand, it was possible to adjust the moisture content in any crock to any desired percentage.

In order to have uniform conditions for nodule formation the soil in each crock was not only thoroughly inoculated with a water suspension of the proper organism, but also was maintained at 20% moisture. The crocks were kept standing in running water so that temperature conditions for all would be alike. Frequent weighings, sometimes twice daily, and the addition of distilled water kept the moisture content reasonably uniform.

Red kidney beans were planted on July 22, about 10 to 12 for each crock. On August 14 inspection showed plants to be well nodulated, giving an average of at least 30 nodules to the plant. At this period desiccation was begun. The crocks were divided into groups of four and the moisture spontaneously reduced to the following percentages: 20, 15, 12.5, 10, and 8. After the moisture reached the desired percentage it was maintained at this content for one day and then brought back to the original 20%.

SHEDDING OBSERVATIONS

Observations were made on September 9. The plants were just beginning to bloom. Those in crocks where the moisture had been reduced to 10 and 8% were showing the effects of such a treatment. The lower leaves were beginning to turn yellow and in some cases to fall off. After the plant roots were freed from soil by gently washing them with a stream of water they were examined. The physical condition and number of nodules that remained on plant roots which had been desiccated to the varying percentages of moisture were observed. The data, together with other notes that seem desirable, are shown in Table 1.

TABLE 1.—*Effect of moisture reduction from that which was present when nodulation occurred on the number and the physical condition of the nodules on red kidney beans.*

Percentage moisture reduced to	Number of nodules remaining on each plant	Affected nodules		Condition of affected nodules
		Number	%	
20*	35, 13, 53, 14, 78, 43, 54, 25, 61, 90, 51, 84, 58, 72, 106, 113, 86, 101, 101, 112, 110	None	None	
15	75, 64, 89, 82, 130, 32, 39, 18, 28, 35, 23, 60, 48, 57, 72, 50, 84, 44, 42, 38	11 20 11	0.04	Soft and float on water
12.5	48, 47, 72, 46, 80, 52, 112, 51, 49, 43, 85, 50, 89, 54, 36	26, 26, 28, 15, 46, 22, 35, 15, 19, 18, 44, 35, 50, 33, 20	36.00	Soft and float on water. Some hollow, some very brown
10	35, 55, 66, 57, 52, 34, 25, 52, 109, 44, 29, 24, 53, 46, 70, 34, 70, 30, 70, 9, 17	0, 0, 0, 20, 14, 15, 8, 0, 18, 9, 0, 0, 13, 0, 0, 0, 17, 16, 24, 6, 12	15.00	Soft and float on water; none hollow; 24 dislodged from plant roots and dark
8	33, 44, 79, 57, 21, 50, 103, 50, 41, 30, 41, 64, 104, 65, 11, 39, 55, 23, 89, 29, 48, 38, 19, 28	Not determinable		About 50 floaters; some badly decayed; others unhealthy but no visible signs of decay

*Present when nodulation occurred.

The records are typical of several such tests. They indicate clearly that a reduction in moisture of a few per cent for 24 hours from that which was present when nodulation occurred resulted in a shedding of nodules. A drop in moisture from 20 to 12.5% destructively affected 432 of 1,346 nodules. This was over 36%. Individual plants showed as high as 57% of the nodules to be affected. Some of the affected nodules were light enough to float on water, some were soft, while all that was left of others was an empty hull. The latter were characterized by a brown or dark color. Many of those that were not visibly affected were undoubtedly less vigorous and of reduced value to the plant.

Many of the nodules recorded in the table as remaining on plants at harvest time were in reality some that had developed between the end of the desiccation period and harvest time. This was judged partly from the small size and fresh appearance which they exhibited and partly from the average number of nodules on plants

when desiccation was started in comparison with those present at harvest time on plants constantly kept at a uniform moisture content. Shedding of nodules occurred more readily on the small and fibrous roots than on the tap root or from locations near the tap root. The mechanism by which the nodules were shed was not observed. There was no evidence that the contraction of the soil during desiccation took part in the process. Most of the nodules affected were still in contact with the root, and decay seemed to begin on the inside of the nodule. In a similar experiment a drop in moisture from 25 to 20% also caused a similar shedding of nodules.

It required a considerably longer time to desiccate the soil to 10 or 8% moisture than to 15 or 12.5%. This means that those plants which grew in soils desiccated to 10 or 8% had a shorter period of growth after desiccation, and consequently a shorter time for the decay of affected nodules, before being examined than did those plants which grew in soil desiccated to 15 and 12.5% moisture. This made it difficult to determine how many of the nodules were affected and may account for the observed condition of nodules on those plants from crocks where the moisture was reduced to 10 and 8%.

DISCUSSION

These results offer a reasonable explanation for the failure of numerous investigators to obtain beneficial results from artificial cultures, particularly on beans, and suggest why such cultures may sometimes reduce bean yields. Once a plant has formed numerous nodules, as is often the case in wet soil in early spring, and subsequently encounters a dry period before maturity it may shed many nodules. When the moisture is again increased new infections occur. This process of nodulation and shedding of nodules, in various degrees of completeness, may happen several times during the life of the plant. The effect of such recurring nodulation and its resulting intermittent service to the plant may stunt it so badly that final growth may be considerably less. Early growth in the presence of high moisture with accompanying stimulated nodule production brought about by the use of artificial cultures may produce a plant that can not readily adjust itself to drastic moisture changes which may often occur before plant maturity.

These findings also aid in the interpretation of many conflicting data, particularly those relating to nodular counts on plants at or near blooming time. Such data are without question subject to considerable experimental error and should not be given too much credence unless one knows the moisture conditions to which the plants have been subjected before the observations are made.

Although the observations presented were made on young bean plants, there seems to be no reason why the effect of desiccation on nodules should not apply to many other legumes.

CONCLUSION

Plants were grown in soil whose moisture content was controlled. After nodulation had occurred the moisture content of the soil was reduced to definite values for 24 hours and the effect on the existing nodules observed. The outstanding observations are listed below.

A reduction of soil moisture from 20 to 12.5% caused bean roots to shed on the average about 36% of their nodules. Some individual plants showed 57% of their nodules to be destructively affected by this drop in moisture. Shedding occurred more freely on small and fibrous roots than on larger roots.

BOOK REVIEWS

THE SOIL AND THE MICROBE

By Selman A. Waksman and Robert L. Starkey. New York: John Wiley & Sons, Inc. XI+260 pages, illus. 1931. $3.50.

This book is well organized, easy to read, and the passing from one heading to another is accomplished logically and smoothly. From the wealth of illustrations, figures, chemical equations, and tables now available in the literature, the authors have selected excellent material to illustrate the subject matter. The title might well be "The Plant, the Soil, and the Microbe," for the space given to plants, plant residues, and organic matter in general is considerable. The book may be considered a rather full abstract of *Principles of Soil Microbiology*, which was written by the senior author. (Reviewed in this JOURNAL, Vol. 20:1238. 1928.)

The material treated is grouped under the following chapter headings: I. The Soil and the Plant; II. The Microbe and Its Activities; III. The Soil Population and Its Distribution; IV. Rôle of Microbes in the Decomposition of Organic Substances in the Soil; V and VI. Transformation of Nitrogen by Soil Microbes; VII. Transformation of Mineral Substances in Soil through the Direct or Indirect Action of Micro-organisms; VIII. Interrelationships Between Higher Plants and Soil Micro-organisms; IX. Modification of Soil Population; and X. Importance of Microbes in Soil Fertility. Many conclusions and summaries not found in *Principles of Soil Microbiology* are given in the various chapters. The equations are serviceable to persons who already know something about biological processes, but to the beginner many of them are of little value.

The book can be used as a text provided it is supplemented with lectures. One wonders, however, concerning the accuracy and the value of such data as that compiled in Table 27 (page 123), concerning the amounts of nitrogen fixed by various legumes, which probably represents the viewpoint and interpretation of numerous workers.

No literature is specifically reviewed, although at the end of each chapter references are given which probably were used as a basis for the statements in the chapter. Persons wishing statements of experimental facts and conclusions from experimental work without a great deal of actual data will find this book very serviceable. (J. K. W.)

SOIL HANDBOOK

By Hellige, Inc., New York City. XXVIII + 112 pages, illus. 1931. Paper cover. 90 cents.

This little handbook, designed primarily to accompany the various types of soil test outfits manufactured by the publisher and with a large section given over to directions for the use of Hellige soil testing apparatus, contains, in addition, much useful information for the soil specialist, even though necessarily elementary in its treatment of the subject. It would seem to be particularly well adapted for use in the field.

Following brief discussions of soil reaction and soil chemistry, the precision of pH measurements is touched upon and considerable space given to a discussion of means of adjusting soil reaction to a required point. An especially helpful section in this part of the book is an extended list of plants with the optimum soil reaction for each plant.

Also of interest to many will be the brief sections on lawns and golf greens, greenhouse soils, and soil reaction for vegetables, together with information on the testing of soils for readily available phosphorus. (J. D. L.)

AGRONOMIC AFFAIRS

MEETING OF THE NORTHEASTERN SECTION OF THE SOCIETY

The Northeastern Section of the Society held an evening banquet meeting June 24, 1931, in connection with the Soil Fertility Conference commemorating the fiftieth anniversary of the founding of the fertility plats at Pennsylvania State College. Seventy-five members and guests were in attendance. A short business meeting was held immediately after the banquet. Reports of progress and plan of work of the three committees on Soil Organic Matter, Pasture Investigations, and Fertilizer Ratios were made. These reports were heartily approved and indicated valuable results for the future.

A canvass of members indicated that a summer meeting was decidedly preferable to a winter meeting. On the invitation of the New York State Experiment Station at Geneva to meet there in 1932 to help celebrate the fiftieth anniversary of the founding of that Station, it was voted to hold the regular annual meeting at Geneva and Ithaca, probably in June, 1932.

Agronomists from eastern Ohio informally invited the Section to hold a summer meeting at Wooster. Indications are that the Section should logically include this group as regular members.

The present officers, including T. E. Odland of Rhode Island, *President;* H. B. Sprague of New Jersey, *Vice-President;* and M. H. Cubbon of Massachusetts, *Secretary-Treasurer;* were reelected for the coming year.

THE PENNSYLVANIA SOIL FERTILITY CONFERENCE

About 125 agronomists and others, representing a large number of institutions from all parts of the country, registered for the Soil Fertility Conference held at Pennsylvania State College June 24 to 26 in commemoration of the fiftieth anniversary of the laying out of the soil fertility plats at that institution. In honor of the late Dr. W. H. Jordan, who laid out these plats in 1881 and who was to have been the guest of honor at the Conference, the Board of Trustees of Pennsylvania State College formally designated the field the "Jordan Soil Fertility Plots," and a suitable marker to that effect was erected on the field at the beginning of the Conference.

In addition to inspection trips to the old fertility plats and to outlying experiment fields, a number of technical papers were presented at the formal sessions and will be published in abstract form in a technical bulletin soon to be issued by the Pennsylvania Experiment Station. Following is a list of the papers:

Origin, Nature, and Extent of the Hagerstown Soil, A. L. Patrick. Discussion by C. F. Marbut.

The Old Fertility Plots; Economic Returns from Plot Treatments, F. D. Gardner. Discussion by C. E. Thorne.

Nitrification in Relation to Plot Yields, C. D. Jeffries. Discussion by A. B. Beaumont.

Soil Respiration in Relation to Plot Yields, F. J. Holben. Discussion by S. A. Waksman.

Effect of Fertilizer Treatments on the Content of Exchangeable Cations in Hagerstown Soil, F. G. Merkle. Discussion by Richard Bradfield.

Nitrogen Balance in a Four-year Grain Rotation, J. W. White. Discussion by J. A. Bizzell.

Reciprocal Effects of Nitrogen, Phosphorus, and Potassium on Absorption by Plants, Walter Thomas. Discussion by Emil Troug.

The Comparative Effects of Different Phosphates on Yield and Maturity, C. F. Noll. Discussion by S. D. Conner.

The Early History of the Old Fertilizer Plots, Enos H. Hess.

Fifty Years of Soil Fertility Investigations, H. G. Knight.

The Nitrogen Outlook, J. G. Lipman.

PLANT BREEDING ABSTRACTS

The Imperial Bureau of Plant Genetics at Cambridge, England, has begun to issue a publication entitled *Plant Breeding Abstracts* in which all the more important current publications dealing with plant breeding and the genetics of crop plants are listed. The references are classified according to subject and each reference is followed by an abstract indicating the subject matter of the paper and the results obtained. The papers are divided into two halves, those published in the British Empire and those published in foreign countries. Papers written in foreign languages are usually abstracted somewhat more fully than papers in English. *Plant Breeding Abstracts* is issued quarterly and Vol. 1, No. 3, which was published on April 1, 1931, contains 197 references covering 52 pages.

The annual subscription for the publication is at present 5/- post free, single copies being obtainable at the price of 1/6. Subscriptions should be sent to the Deputy Director, Imperial Bureau of Plant Genetics, School of Agriculture, Cambridge, England.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 SEPTEMBER, 1931 NO. 9

INHERITANCE OF SEED WEIGHT AND LINT INDEX RELATED TO HEREDITABILITY OF LINT PERCENTAGE IN COTTON[1]

J. O. WARE[2]

In a recent paper (4)[3] studies in the inheritance of lint percentage based upon data obtained from four sets of crosses in cotton were reported. The four sets of crosses were designated as A, B, C, and D. The A crosses were between three Pima (Egyptian type, *Gossypium barbadense*) plants used as females and one Winesap[4] (Upland type, *G. hirsutum*) plant used as the male. The B crosses were between two Pima plants used as females and one Upright (Upland type) plant used as the male. The C cross[5] was between one Winesap plant used as the female and one Sea Island (Sea Island type, *G. barbadense*) plant used as the male. The D crosses were between several sparse-linted plants and several normal-linted plants, all of the Upland type.

In the D crosses, high lint percentage was shown to be incompletely dominant in the F_1 generation. In the F_2 generation and in the progeny of the back cross on the sparse-linted parent, there were good evidences of a single factor control of lint percentage. The F_1 generation mean of the C cross also took an intergrade position between the two parental means, but in the A and B crosses it lay respectively below both of its parental means. Thus high lint per-

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Research Paper No. 246 Journal Series, University of Arkansas. Received for publication January 29, 1931.

[2]Agronomist.

[3]Reference by number is to "Literature Cited," p. 702.

[4]The Winesap variety is characterized by red plant color for which the anthocyanic pigment in the sap is responsible.

[5]The author was in error in giving the direction of the C cross in the former paper.

centage was incompletely dominant in the C and D crosses and low lint percentage was intensified in the A and B crosses. The question arises, why should high lint percentage tend to be transmitted in two of these hybrid sets, and low lint percentage, to the point of intensification, tend to be transmitted in the other two?

The object of this paper is to submit additional data on the seed weight and the lint index from the first three sets of crosses, to analyze further the apparent discrepancy of lint percentage inheritance as exhibited in the first generations of these crosses, and to report the heritable tendencies of the seed weight and the lint index characters themselves.

METHOD OF WORK

The procedure in conducting the crossing, the selfing, and the carrying out of the work in general is described in the preceding publication (4). For the present presentation, the weight of 100 seeds was taken and the lint index determined from the plants used in the A, B, and C crosses. This type of data from the D crosses has not been obtained.

PRESENTATION OF DATA

As in the lint percentage studies, for each of the three sets of crosses, A, B, and C, six assemblages of plants are made. They are the female parental strain, the male parental strain, the F_1 generation, the two sesqui-hybrid aggregations, and the F_2 generation. The six populations representing the A crosses (Pima X Winesap), the six representing the B crosses (Pima X Upright), and the six representing the C cross (Winesap X Sea Island) for the seed weight are given in Table 1 and for the lint index in Table 2. The frequency distribution, the number of individuals, the mean, the standard deviation, and the coefficient of variability for each population are shown. The number of plants for a given population does not always entirely coincide for both seed weight and lint index. The variation in numbers, however, is slight and is due to an individual going occasionally too far beyond the outer rim of scatter to be included as a member of the group. These widely deviated apparitions probably are more attributable to environment or to mechanical errors than to genetic behavior. The same plant may have been within bounds for seed weight, but without for lint index and vice versa. Out of bounds fluctuations are responsible for the difference in numbers between given populations of this paper and those of the lint percentage paper (4), except in the Winesap parental strain of the A crosses,

in the Pima parental strain of the A and B crosses, and in the F_1 generation of the A crosses. These specially mentioned populations included more plants for the present work. The weight of seed and lint index determinations were made on larger numbers in these particularly cited groups than were included for lint percentage.

The actual numbers of plants are given in the tables, but for the purpose of better comparing a given population with its parental populations, or with its offspring populations, all frequencies were converted to a percentage basis. The conversion of each frequency in a population to a percentage of the total number in that population permits each frequency curve, when plotted, to include the same area. The seed weight frequency curves for the A crosses are shown in Fig. 1, for the B crosses in Fig. 2, and for the C cross in Fig. 3. The lint index frequency curves for the A crosses are given in Fig. 4, for the B crosses in Fig. 5, and for the C cross in Fig. 6.

In Table 3 are assembled determinations for lint percentage, seed weight, and lint index in the three sets of crosses for the purpose of analyzing the F_1 generation inheritance in respect to the three characters.

DISCUSSION OF RESULTS

Three degrees of difference in lint percentage were represented by the three sets of crosses (Table 3). The means of the A parental strains differed by 0.93 ± .24%, that of the B parental strains by 7.38 ± .31%, and that of the C parental strains by 9.90 ± .25%. The lint percentage frequency distribution curves (4) for the two parental strains practically coincide in the A crosses, slightly overlap in the B crosses, but are completely separated in the C cross. None of the parental strain means of the hybrid sets for either the weight of seeds or the lint index were greatly differentiated. The mean parental strain seed weight difference in the A crosses was 2.50 ± .115 grams, in the B crosses 1.81 ± .106 grams, and in the C cross 2.00 ± .159 grams. The mean parental strain lint index difference was in the A crosses 0.86 ± .054, in the B crosses 0.37 ± .050, and in the C cross 1.10 ± .078. The frequency curves of the parental strains for both seed weight and lint index in each of the three sets of crosses overlapped more or less.

However, between varieties or types of the cotton plant, the contrast in seed weight or in lint index is not as great as it sometimes is in lint percentage. The parental strains in none of the crosses were sufficiently removed from each other in either seed weight or lint index to afford the best sort of material for a

TABLE 1.—*Frequency distributions, numbers of individual plants, means, standard deviations, and vari-*

Generation or population	Frequency of the weight of 100 seeds in grams																		
	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5
									A Cross										
1*	–	–	–	1	1	17	32	32	24	21	16	8	8	5	3	—	—	—	—
2	–	–	–	–	–	1	1	1	3	5	2	8	11	14	11	14	8	4	2
3	–	–	–	–	–	–	–	–	–	1	2	3	7	13	17	26	27	13	13
4	1	0	1	4	2	8	15	14	16	35	39	36	46	40	23	27	17	16	4
5	–	–	1	1	3	4	2	2	3	8	7	3	13	14	6	12	12	15	16
6	1	1	1	3	3	13	4	10	9	20	10	15	17	11	20	10	15	13	14
									B Cross										
7	–	–	–	–	3	2	0	9	28	42	60	24	5	1	0	1	—	—	—
8	–	–	–	–	–	1	1	1	3	5	2	8	11	14	11	14	8	4	2
9	–	–	–	–	–	–	–	–	–	1	5	3	4	6	12	9	10	15	19
10	–	–	–	–	–	–	–	2	3	10	6	19	20	28	16	11	7	8	5
11	–	–	–	–	–	–	–	–	–	3	1	0	3	1	4	5	5	2	5
12	–	–	–	2	2	6	3	8	7	7	6	12	20	22	16	26	22	18	10
									C Cross										
13	–	–	–	–	–	–	–	5	8	11	15	7	4	0	2	–	–	–	–
14	–	–	–	–	–	–	–	–	1	4	6	3	10	1	7	7	4	3	4
15	–	–	–	–	–	–	–	1	1	0	2	1	6	6	5	5	9	7	4
16	–	–	–	–	–	–	–	–	6	0	8	3	5	8	8	3	8	2	5
17	–	–	–	–	–	–	–	–	–	2	5	3	1	4	6	4	4	4	4
18	1	2	5	4	1	4	3	6	6	6	7	8	11	14	12	11	12	7	3

*1. Winesap parental strain
2. Pima parental strain
3. F_1 (Pima x Winesap)
4. B. C. (F_1 x Winesap)
5. B. C. (F_1 x Pima)
6. F_2 generation
7. Upright parental strain
8. Pima parental strain
9. F_1 (Pima x Upright)
10. B. C. (F_1 x Upright)

TABLE 2.—*Frequency distributions, numbers of individual plants, means, standard deviations, and vari-*

Generation or population	Frequency of lint index																	
	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75
									A Cross									
1*	–	–	–	–	–	–	–	2	10	16	23	25	34	26	12	9	10	0
2	–	–	–	–	–	–	–	–	–	–	–	4	12	8	10	11	9	8
3	–	–	–	–	–	–	2	1	1	1	6	10	15	12	39	25	24	4
4	–	–	–	1	9	7	11	12	32	30	35	45	53	31	36	12	15	8
5	–	–	–	3	4	10	6	5	8	11	12	14	14	15	11	10	8	2
6	3	1	6	6	11	19	7	14	21	26	16	17	16	13	12	12	3	6
									B Cross									
7	–	–	–	–	–	–	–	–	–	–	–	1	2	3	[illegible]	15	33	47
8	–	–	–	–	–	–	–	–	–	–	–	4	12	8	[illegible]	11	9	8
9	–	–	–	–	–	–	–	–	1	0	1	1	8	6	7	14	27	25
10	–	–	–	–	–	–	1	0	1	1	1	6	9	11	22	20	19	17
11	–	–	–	–	1	0	1	2	3	4	3	2	2	5	5	3	2	3
12	–	–	–	–	–	6	10	5	11	11	18	18	19	21	19	16	17	19
									C Cross									
13	–	–	–	–	–	–	–	–	–	–	5	12	17	4	10	3	1	–
14	–	–	–	4	6	1	7	11	6	2	5	4	2	3	2	1	–	–
15	–	–	–	–	–	–	1	0	0	2	2	10	11	6	13	8	8	1
16	–	–	–	–	–	–	–	–	6	5	9	9	6	7	4	1	6	2
17	–	–	–	–	1	2	3	1	1	7	7	10	3	6	2	4	1	2
18	–	–	1	1	4	4	4	11	10	10	13	16	12	12	9	4	7	5

*1. Winesap parental strain
2. Pima parental strain
3. F_1 (Pima x Winesap)
4. B. C. (F_1 x Winesap)
5. B. C. (F_1 x Pima)
6. F_2 generation
7. Upright parental strain
8. Pima parental strain
9. F_1 (Pima x Upright)
10. B. C. (F_1 x Upright)

ability coefficients for the weight of 100 seeds from the populations of the A, B, and C sets of crosses.

Frequency of the weight of 100 seeds in grams										Number of plants in each population	Mean in grams	Standard deviation	Coefficient of variability
15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5				
										A Cross			
–	–	–	–	–	–	–	–	–	–	168	9.49±.059	1.14±.042	12.01± .447
–	–	–	–	–	–	–	–	–	–	85	11.99±.099	1.35±.070	11.25+ .582
7	9	2	3	3	–	–	–	–	–	146	13.45±.076	1.37±.054	10.18± .402
6	4	1	–	–	–	–	–	–	–	355	11.29±.064	1.78±.045	15.76± .398
7	5	5	1	–	–	–	–	–	–	140	12.48±.126	2.21±.089	17.70± .713
11	6	10	1	2	–	–	–	–	–	220	11.86±.113	2.48±.080	20.91± .672
										B Cross			
–	–	–	–	–	–	–	–	–	–	175	10.18±.039	0.76±.027	7.46± .268
–	–	–	–	–	–	–	–	–	–	85†	11.99±.099	1.35±.070	11.25± .582
13	11	6	4	1	1	–	–	–	–	120	13.86±.098	1.59±.069	11.47± .499
–	–	–	–	–	–	–	–	–	–	135	11.90±.072	1.24±.051	10.42± .427
4	1	1	4	–	–	–	–	–	–	39	13.53±.193	1.79±.137	13.22±1.009
10	3	6	9	3	3	2	2	0	3	228	12.75±.110	2.46±.078	19.29± .609
										C Cross			
–	–	–	–	–	–	–	–	–	–	52	10.32±.076	0.81±.054	7.85± .519
4	–	–	–	–	–	–	–	–	–	54	12.32±.140	1.53±.099	12.41± .805
9	1	1	1	0	1	–	–	–	–	60	13.28±.144	1.65±.102	12.42± .764
1	2	2	–	–	–	–	–	–	–	61	12.34±.149	1.72±.105	13.93± .850
5	3	3	3	1	–	–	–	–	–	52	13.38±.181	1.93±.128	14.42± .953
1	2	1	3	0	1	–	–	–	–	131	11.42±.147	2.49±.104	21.80± .908

11. B. C. (F_1 x Pima)
12. F_2 generation
13. Winesap parental strain
14. Sea Island parental strain
15. F_1 (Winesap x Sea Island)
16. B. C. (F_1 x Winesap)
17. B. C. (F_1 x Sea Island)
18. F_2 generation

†The Pima parental strain used in the B crosses is the same population as used in the A crosses. This group included offspring from the selfed Pima parental plants of both the A and B crosses.

ability coefficients for the lint index from the populations of the A, B, and C sets of crosses.

Frequency of lint index										Number of plants in each population	Mean lint index	Standard deviation	Coefficient of variability
6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25				
										A Cross			
1	–	–	–	–	–	–	–	–	–	168	4.43±.029	0.55±.020	12.41± .456
11	8	–	–	–	–	–	–	–	–	81	5.29±.046	0.61±.033	11.53± .611
6	0	1	–	–	–	–	–	–	–	147	4.97±.028	0.50±.020	10.06± .395
5	6	5	2	1	–	–	–	–	–	356	4.35±.031	0.87±.022	20.00± .505
6	2	–	–	–	–	–	–	–	–	141	4.25±.055	0.97±.039	22.82± .911
6	2	–	–	–	–	–	–	–	–	217	3.88±.049	1.06±.034	27.32± .884
										B Cross			
40	14	3	–	–	–	–	–	–	–	175	5.66±.021	0.41±.015	7.24± .261
11	8	–	–	–	–	–	–	–	–	81†	5.29±.046	0.61±.033	11.53± .611
21	9	2	–	–	–	–	–	–	–	122	5.51±.033	0.54±.023	9.80± .423
6	9	5	3	3	0	2	1	–	–	137	5.39±.045	0.78±.032	14.47± .589
2	2	1	–	–	–	–	–	–	–	41	4.65±1.03	0.98±.073	21.07±1.569
16	4	4	2	6	1	3	1	0	2	229	4.87±.050	1.12±.035	22.99± .724
										C Cross			
–	–	–	–	–	–	–	–	–	–	52	4.57±.036	0.38±.025	8.31± .549
–	–	–	–	–	–	–	–	–	–	54	3.47±.070	0.76±.049	21.90±1.421
1	–	–	–	–	–	–	–	–	–	63	4.79±.047	0.55±.033	11.48± .698
5	1	0	0	1	1	–	–	–	–	63	4.68±.076	0.89±.053	19.01±1.142
3	–	–	–	–	–	–	–	–	–	53	4.31±.079	0.85±.056	19.72±1.292
2	2	3	1	1	–	–	–	–	–	132	4.30±.059	1.01±.042	23.48± .974

11. B. C. (F_1 x Pima)
12. F_2 generation
13. Winesap parental strain
14. Sea Island parental strain
15. F_1 (Winesap x Sea Island)
16. B. C. (F_1 x Winesap)
17. B. C. (F_1 x Sea Island)
18. F_2 generation

†The Pima parental strain used in the B crosses is the same population as used in the A crosses. This group included offspring from the selfed Pima parental plants of both the A and B crosses.

TABLE 3.—*Lint percentage of the F_1 generation and parental strains compared with their weight of 100 seeds and lint index.*

Population	Lint percentage*	Weight of 100 seeds, grams	Lint index
	A Crosses		
Winesap parental strain	31.91±.14	9.49±.059	4.43±.029
Pima parental strain	30.98±.20	11.99±.099	5.29±.046
Parental difference	0.93±.24	2.50±.115	0.86±.054
F_1 generation	26.35±.12	13.45±.076	4.97±.028
F_1 and Pima difference	4.63±.25	1.46±.125	0.32±.057
F_1 and Winesap difference	5.56±.18	3.96±.099	0.54±.040
	B Crosses		
Upright parental strain	36.00±.06	10.18±.039	5.66±.021
Pima parental strain	28.62±.30	11.99±.099	5.29±.046
Parental difference	7.38±.31	1.81±.106	0.37±.050
F_1 generation	28.59±.08	13.86±.098	5.51±.033
F_1 and Pima difference	0.03±.31	1.87±.139	0.22±.057
F_1 and Upright difference	7.41±.10	3.68±.105	0.15±.039
	C Cross		
Winesap parental strain	30.69±.17	10.32±.076	4.57±.036
Sea Island parental strain	20.79±.19	12.32±.140	3.47±.070
Parental difference	9.90±.25	2.00±.159	1.10±.078
F_1 generation	26.44±.15	13.28±.144	4.79±.047
F_1 and Sea Island difference	5.65±.24	0.96±.201	1.32±.084
F_1 and Winesap difference	4.25±.22	2.96±.163	0.22±.059

*Taken from Tables 2, 3, and 4, pages 884 and 885, Vol. 21, of this JOURNAL.

genetical analysis of the hereditability of these characters. The parental contrast was not large enough to permit modal formations in the segregating generations and thus show character differentiation in these subsequent populations. On the other hand, similarity in magnitude in the allelomorphs furnishes better data than widely differentiated character pairs for measuring the transmission of hybrid vigor from the first generation to later generations. This condition seemed to be true for plant height in the B crosses and is discussed in a previous paper (5). Definite character expression stood out both for seed weight and lint index in the conjugate generation of all three sets of hybrids.

THE F_1 GENERATION COMPARED WITH PARENTS

When the seed weight and the lint index of the F_1 generation and the respective parental strains are compared along with lint percentage (Table 3), another interpretation for the inheritance of the latter character is evident. These comparisons for each set of crosses taken up separately.

The A crosses.—In the A crosses the lint percentage of the Winesap parental strain was slightly higher than that of the Pima parental strain, while both the seed weight and the lint index were larger in the Pima parental strain than in the Winesap parental strain. The lint percentage in the Pima parental strain was $0.93 \pm .24\%$ lower than in the Winesap parental strain. The former parental strain had a lower lint percentage than the latter parental strain, not because the

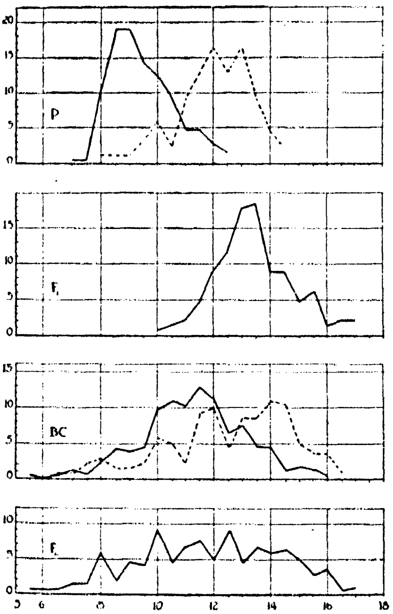

FIG. 1.—Weight of 100 seeds, A crosses, Pima X Winesap. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the weight of 100 seeds in grams. The solid curve line in the P section of the graph represents the Winesap parental population and the broken curve line the Pima parental population. The solid curve line in the BC section of the graph represents the population from the back cross on the Winesap parental strain and the broken curve line the population from the back cross on the Pima parental strain. What the curves in the F_1 and F_2 sections show is obvious.

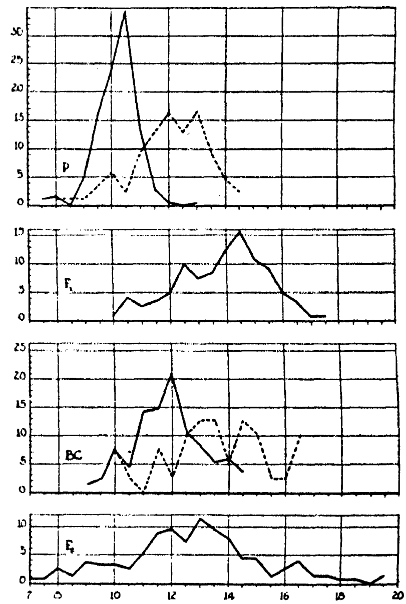

FIG. 2.—Weight of 100 seeds, B crosses, Pima X Upright. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the weight of 100 seeds in grams. The solid line in the P section of the graph represents the Upright parental population and the broken curve line the Pima parental population. The solid curve line in the BC section of the graph represents the population from the back cross on the Upright parental strain and the broken curve line the population from the back cross on the Pima parental strain. What the curves in the F_1 and F_2 sections show is obvious.

actual yield of lint was smaller, but because the seeds were heavier. The actual yield of lint was higher in the Pima parental strain as indicated by the lint index. The lint index in the Pima parental strain was $0.86 \pm .054$ more than the lint index of the Winesap parental strain.

The lint percentage in the F_1 generation showed a marked decrease or suppression from that of the parental strains, but this reduction does not exist in the lint index. Lint index as exhibited in the A

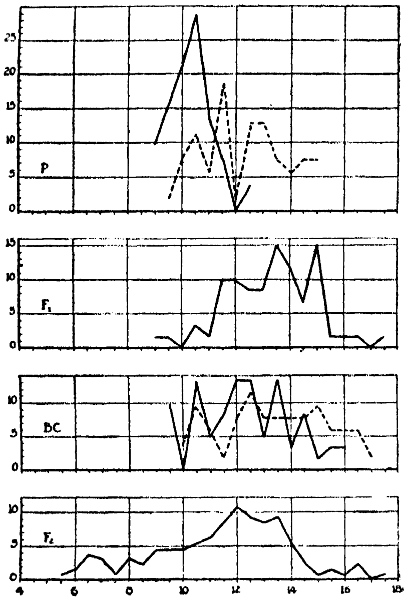

FIG. 3.—Weight of 100 seeds, C cross, Winesap X Sea Island. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the weight of 100 seeds in grams. The solid curve line in the P section of the graph represents the Winesap parental population and the broken curve line the Sea Island parental population. The solid curve line in the BC section of the graph represents the population from the back cross on Winesap parental strain and the broken curve line the population from the back cross on the Sea Island parental strain. What the curves in the F_1 and F_2 sections show is obvious.

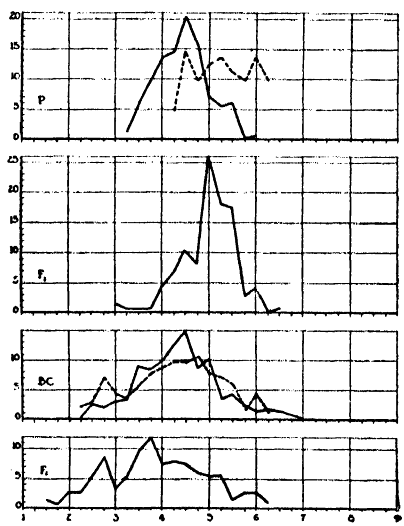

FIG. 4.—Lint index, A crosses, Pima X Winesap. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the lint index or the weight of fiber from 100 seeds in grams. The solid curve line in the P section of the graph represents the Winesap parental strain population and the broken curve line the Pima parental strain population. The solid curve line in the BC section of the graph represents the population from the back cross on the Winesap parental strain and the broken curve line the population from the back cross on the Pima parental strain. What the curves in the F_1 and F_2 sections show is obvious.

crosses should be classified as incompletely dominant for it is higher than the intermediate point between the lint indexes of the two parental strains. The F_1 lint index is 0.54 ± .040 higher than that of the lower (Winesap) parental strain and 0.32 ± .057 lower than that of the higher (Pima) parental strain. The suppression of the lint percentage in the F_1 generation of the A crosses is attributable to the hybrid vigor expressed in the weight of the seeds. The weight of 100 seeds in the first generation was 3.96 ± .099 grams higher than that of the Winesap parental strain and 1.46 ± .125 grams higher than that of the Pima parental strain.

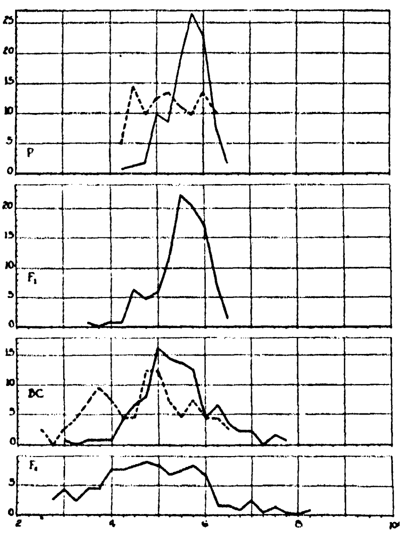

FIG. 5.—Lint index, B crosses, Pima X Upright. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the lint index or the weight of fiber from 100 seeds in grams. The broken curve line in the P section of the graph represents the Pima parental population and the solid curve line the Upright parental population. The broken curve line in the BC section of the graph represents the population from the back cross on the Pima parental strain and the solid curve line the population from the back cross on the Upright parental strain. What the curves in the F_1 and F_2 sections show is obvious.

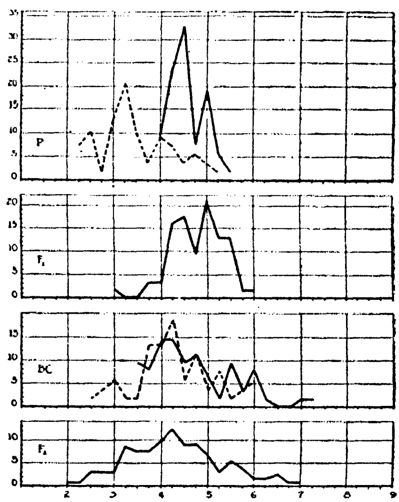

FIG. 6.—Lint index, C cross, Winesap X Sea Island. The ordinate numerals indicate the number of plants as a percentage of the total frequency population. The abscissa numerals denote the lint index or the weight of fiber from 100 seeds in grams. The broken curve line in the P section of the graph represents the Sea Island parental population and the solid curve line the Winesap parental population. The broken curve line in the B C section of the graph represents the population from the back cross on the Sea Island parental strain and the solid curve line the population from the back cross on the Winesap parental strain. What the curves in the F_1 and F_2 sections show is obvious.

The B crosses.—In the B crosses the lint percentage of the Upright parental strain was considerably higher than that of the Pima parental strain. The lint index was only slightly higher in the Upright parental strain than in the Pima parental strain. The weight of 100 seeds in the Upright parental strain was somewhat lower than in the Pima parental strain. In the Pima parental strain, the lint percentage was 7.38 ± .31 lower than in the Upright parental strain. The weight of 100 seeds in the Pima parental strain was 1.81 ± .106 grams higher than in the Upright parental strain, and the lint index 0.37 ± .050 lower than in the Upright parental strain. There was much more spread between the parental lint percentages in the B crosses than in the A crosses, but the difference between the parental seed weights in the B crosses was less than in the A crosses. Consequently, the much lower lint percentage of the Pima parental strain under that of the Upright parental strain was reflected in the lint indexes. Where the seed weights of two compared strains are identical, the lint percentage and the amount of lint expressed by the lint index are positively correlated, but where a light-seeded variety and a heavy-seeded variety are being evaluated for lint yields, the lint percentage may be a poor criterion of measurement.

The mean lint percentage of the F_1 generation is a shade lower (though not significantly lower) than the mean lint percentage of the lower (Pima) parental strain. In this case, low lint percentage is considered completely dominant and might be construed as indicating the inheritance of decreased lint amount were the weight of seeds and the lint index not taken into account. The inheritance of the weight of seeds and of the lint index furnishes a different interpretation for this example of lint hereditary transmission. The lint index in the F_1 generation has increased over the lower percentage and lower lint index (Pima) parental strain. The amount of lint should be classified as incompletely dominant (F_1 means coming above the midpoint between the two parental means and not approximating the position of the higher mean are considered as incompletely dominant) as the F_1 mean is 0.22 ± .057 above the lower (Pima) parental mean and 0.15 ± .039 below the higher (Upright) parental mean. The apparent dominance of low lint percentage in the B crosses is not the inheritance of low lint quantity, but the result of intensified weight in the conjugate hybrid seeds. The weight of 100 seeds in the F_1 population was 3.68 ± .105 grams higher than that of the lighter seeded (Upright) parental strain and 1.87 ± .139 grams higher than that of the heavier seeded (Pima) parental strain.

The C cross.—In the C cross the lint percentages of the two parental strains were wide apart in degree, while the parental seed weights

and the parental lint indexes were not separated to such a marked extent. The lint percentage of the Sea Island parental strain was 9.90 ± .25 lower than that of the Winesap parental strain. The lint index of the former was also lower than in the latter by 1.10 ± .078. On the other hand, the weight of 100 seeds in the Sea Island parental strain was 2.00 ± .159 grams higher than the weight of 100 seeds in the Winesap parental strain. The amount of lint produced by the Sea Island parental strain is less than the yield of the Winesap parental strain, but the production of the former strain is not as much lower than that of the latter strain as the percentage of lint difference in the two parental strains indicates. The percentage of lint in the Sea Island parental strain is unduly depressed as compared with the Winesap parental strain. The enlarged difference between the two parental strains shown by the lint percentages and the smaller difference between these parental groups indicated by the lint indexes are attributable to the fact that the seeds of the Sea Island are heavier than the seeds of the Winesap.

Contrary to what was found for the F_1 lint percentage in the A and B crosses, the conjugate hybrid lint percentage in the C cross lay at an intergrade point between those of the two parental strains. The F_1 lint percentage mean was 5.65 ± .24 higher than the lower (Sea Island) parental lint percentage mean and 4.25 ± .22 lower than the higher (Winesap) parental lint percentage mean. The lint index of the F_1 generation showed slight, but significant, intensification. The mean lint index in the first generation was 1.32 ± .084 higher than that of the lower (Sea Island) parental strain and 0.22 ± .059 higher than that of the higher (Winesap) parental strain. Based upon the lint percentage, the yield of lint appears to be incompletely dominant, but founded upon the lint index, the amount of lint is intensified. As in the A and B crosses, the difference in the inheritance of lint, indicated by lint percentage, on the one hand, and by lint index, on the other, is brought about by the expression of hybrid vigor in first generation seed weight. The weight of 100 seeds in the F_1 generation in the C cross was 0.96 ± .201 gram higher than the heavier seeded (Sea Island) parental strain and 2.96 ± .163 grams higher than the lighter seeded (Winesap) parental strain.

The three sets of crosses compared.—The comparison of seed weight and lint index with lint percentage in the F_1 generation of the three sets of crosses shows the heritable relationship of these three elements or characters to each other. This comparison points out the fact that highness or lowness of lint percentage depends both upon the weight of seeds and the amount of lint per seed. Since the magnitude of lint

percentage is dependent upon two physical parts of the plant, lint percentage inheritance can hardly be based upon a single factor pair. The monohybrid ratios obtained in the D crosses, already referred to (4), occurred because the sparse-linted parents and the normal-linted parents were sufficiently removed from each other in lint percentage to allow the F_2 generation and the progeny from the back crossed recessive to absorb any error due to the seed differential and still modalize into clear-cut groups. The sparse-linted and normal-linted types both probably bore seeds of about the same weight and it is likely that these crosses did not possess as much heterosis in seed weight as is exhibited in hybrids between species.

Of the characters that intensify in cotton species hybrids, attention has been called in a recent paper (5) to the fact that there is less display of hybrid vigor in these characters when varieties of the same species are crossed than when species are hybridized. Also, Balls (1), in an inter-Egyptian cross of Sultani X Afifi, did not obtain F_1 intensification in seed weight.

HERITABLENESS OF SEED WEIGHT AND LINT INDEX

Independent studies of seed weight and of lint index have been made. The data for these characters are presented in Tables 1 and 2 and in the graphs. Only the parental strain means and the F_1 generation means were considered in the comparisons of seed weight and lint index with lint percentage. The sesqui-hybrids and the F_2 generations, as well as the frequency distribution of all populations, are included in the seed weight and the lint index studies.

The parental material.—As heretofore stated, the parents in none of the crosses were widely separated for either weight of seeds or lint index. For the study of size or quantitative inheritance, the parents carrying the contrasting characters should be widely removed in degrees of difference to obtain segregation or modal expression in generations subsequent to the first hybrid generation. The parental plants must also be uniform or homozygous for the character under study. However, it is difficult to ascertain absolutely whether or not a given plant is homozygous for a quantitative character. The degree of uniformity possessed by the parental plants used in the present work can be determined by the amount of variation in the parental strains and in the F_1 generation.

East (2), working with quantitative inheritance in tobacco, says, "Crosses between individuals belonging to races, which from long continued self fertilization or other close inbreeding approach a homozygous condition, should give F_1 populations comparable to

the parental races in uniformity." The curves (Figs. 1 to 6) and the coefficients of variability (Tables 1 and 2) of the parental strains and of the F_1 generation depict the type of material used in the seed weight and lint index studies. These results show that none of the parents were ideal in uniformity, but some of them approached more nearly a desirable degree of homozygosity than others. The plants chosen were, no doubt, as uniform for the characters concerned as could be had. Preparation of ideal material with which to start would require not only several years of self breeding, but also rigid selection of the character to be used. It would be very desirable that the parental races be uniform in this work, as the nearer together the allelomorphic means the more necessary it is that the antithetic characters each possess a high degree of uniformity.

The A parents, seed weight.—The A parents each present a fair degree of uniformity. The curves representing their progeny show some skewness, notching, and several wide departures, but the general assumption of the graphs indicates that the respective populations fluctuate around a single mode. The Pima parental strain, however, shows more dispersion than the Winesap parental strain. The F_1 population is monomodal and is slightly more symmetrical than either parental strain, but it has a slightly wider base than either of the parental groups. The coefficient of variability in the conjugate generation is less than that of either parental strain. On the whole, the F_1 generation is more uniform than either parental population.

The A parents, lint index.—The Winesap A parent for lint index is reasonably uniform. The curve for its progeny shows less skewness and presents a more desirable appearance for this character than it does for seed weight. On the other hand, the Pima A parent is less uniform for lint index than it is for seed weight. The curve for the parental strain is much more asymmetrical for the former character than for the latter character. The coefficient of variability for the Pima parental strain is slightly less than that of the Winesap parental strain, however. The F_1 population for lint index is unimodal, but is more skew than for seed weight. There are a few more wide departures in the F_1 generation for lint index than for seed weight. The F_1 graph for lint index has a wider base than the curves for either parental strain has for this character. The lint index coefficient of variability, on the other hand, is less in the F_1 generation than it is in either of the parental strains. Within each of the three populations, the Winesap parental strain, the Pima parental strain, and the F_1 generation, the lint index and the weight of seeds showed coefficients of variability corresponding in size, that is, the same

group of plants in each of the three cases had coefficients of similar magnitude for the two characters. Lint index was practically no more variable than the weight of seeds and vice versa.

The B parents, seed weight.—The Upright parental strain graph indicates a much higher degree of uniformity for seed weight than is shown in the Pima parental strain for this character. The latter strain is the same one used in the A set of crosses. The coefficient of variability is also much lower in the Upright offspring population than it is in that of the Pima parents. The F_1 population curve is monomodal, is not so very skew, but does have some rather deep notching. Its base is somewhat wider than that representing either parental strain. The coefficient of variability of the F_1 population is a shade larger than that of the Pima parental strain and much larger than that of the Upright parental strain. In general, the variability of the F_1 generation corresponds fairly well with the variability of the Pima parental race, but it shows much more fluctuation than is exhibited by the Upright parental race.

The B parents, lint index.—The Upright parental strain graph shows a high degree of uniformity for lint index. Its general appearance indicates about the same degree of uniformity as was found in this strain for seed weight. In the Upright parental population, the coefficient of variability for lint index is a shade less than it is for seed weight, but the difference between the constants for the two characters is not significant. The Pima parental strain graph, as it did in the seed weight, shows much less uniformity than does the Upright parental strain curve. In fact, it is less symmetrical in appearance than it is for seed weight. In this parental strain, the coefficient of variability is slightly less for seed weight than it is for lint index; however, statistically there is no real difference in variation between the two characters. The F_1 population indicates monomodality, but the curve has a bulge of departure at the base of the lower side which gives this figure a wider base than that of either parental strain. With this exception, the general appearance of the F_1 graph is nearly as good as that of the Upright parental strain. The coefficient of variability of the F_1 generation is considerably higher than that of the Upright parental strain, but it is much lower than that of the Pima parental strain. In the F_1 generation, the coefficient of variability is much less for lint index than it is for seed weight. The coefficients of variability for the two characters correspond closely for each parental strain, but as just stated lint index in the F_1 generation varied less than did seed weight in this generation.

The C parents, seed weight.—The Winesap parental strain curve indicates a fair degree of uniformity, but that of the Sea Island

parental strain is very irregular. The deep incisions of the latter's graph indicate modality. The coefficient of variability is much larger in the Sea Island parental strain than it is in the Winesap parental strain. The F_1 generation also shows signs of parental fluctuation. The F_1 graph has a much wider base than that of either parental strain. It is also much notched and incised, but not as deeply cut as the graph of the Sea Island parental strain. The coefficients of variability in the F_1 population and in the Sea Island parental strain are identical, practically. On the other hand, the coefficient of variability in the Winesap parental strain is much lower than it is in the F_1 generation or in the Sea Island parental strain. On the whole, however, the variability for seed weight found in the C cross is greater in the F_1 population than it is in either or both parental populations.

The C parents, lint index.—Neither the Winesap parental strain nor the Sea Island parental strain exhibit a high degree of uniformity for lint index. In the graphs, each appears to divide into modal areas or are very deeply incised due to fluctuations. However, the curve of the Winesap parental strain shows less asymetry than the Sea Island parental strain. The coefficient of variability in the Sea Island parental strain is over two and one-half times that of the Winesap parental strain. The F_1 population graph shows more regularity than that of either parental strain. Its base is wider than that of the Winesap parental strain, but the curve is not as deeply incised as is the case with the Winesap parental strain. The F_1 population tends to be bimodal, although the modality may be due entirely to variation as might have been the case also in the parental strains. The size of the coefficient of variability in the F_1 generation is much nearer to that of the Winesap parental strain than it is to that of the Sea Island parental strain. According to the coefficients of variability, the F_1 generation for lint index is somewhat more variable than the Winesap parental strain and much less variable than the Sea Island parental strain. In the Winesap parental strain, the coefficient of variability is somewhat larger for lint index than it is for seed weight. In the Sea Island parental strain, the coefficient of variability is much larger for lint index than it is for seed weight. On the other hand, in the F_1 generation the coefficient of variability is less for lint index than it is for seed weight.

Seed weight and lint index in parents compared.—The lint index and the seed weight in degree of fluctuation correspond closely with each other in the parental strains of the A and B crosses, the lint index being slightly more variable than the seed weight, except in the

Upright parental strain where seed weight deviated slightly the more of the two characters. None of these differences, however, were statistically real. With the C cross, lint index was apparently more variable than seed weight in the Winesap parental strain and had a coefficient of variability nearly twice as large as that of seed weight in the Sea Island parental strain. In the former parental strain, the difference in variability between the two characters was hardly significant. Of the F_1 populations, the coefficients of variability were a shade to somewhat higher for seed weight than for lint index. This variability difference between the two characters in the F_1 generation for the A crosses is not significant and for the B and C crosses barely indicates a dependable distinction.

Balls (1) says, "The inheritance of the mean seed weight is particularly interesting. In the first place it fluctuates more than any other character, excepting the height, and it further shows clear evidence of autogenous fluctuation." In his comparisons of seed weight and lint weight this investigator continues, "The fluctuation in lint weight seems to be proportionally less than that in seed weight, the P. E. being e. g. $\pm$ 7.5 per cent as against $\pm$ 8.3 per cent, respectively, in the same family." In this instance he was speaking of lint weight in terms of out-turn rather than as expressed by the lint index.

The data presented in this paper, no doubt, have been influenced by autogenous fluctuation, but there are no more evidences of spontaneous deviations in seed weight than in lint index. Also, this work does not bear out the conclusion of Balls that the seed weight is more variable than the lint weight.

THE BACK CROSS AND F_2 GENERATIONS

The position of the mean and the degree of variability for (a) the seed weight and for (b) the lint index are the only observations of any consequence that can be made on the sesqui-hybrids and the F_2 populations through the three sets of crosses. The notches and clefts in the graphs of these perjugate groups may be indications of tendencies to segregate, but the differentiation is not sufficiently pronounced, particularly where the more uniform parentage is involved, to predict any ratios or modal collecting.

SEED WEIGHT

It has been shown heretofore that the seed weight in the first generation of all three sets of crosses was intensified.

Balls (1) has given some data on the inheritance of seed weight. In crosses of Egyptian varieties with Upland varieties, he obtained

hybrid vigor in the F_1 generation, but with an inter-Egyptian cross no intensification was secured. In the latter type of cross, large seeds were merely dominant. In an Afifi (Egyptian type) X Truitt (Upland type) hybrid, the mean seed weight of the former parent was 0.105 gram, that of the latter parent 0.135 gram, and that of the first generation 0.165 gram. In another inter-species cross, Charara (Egyptian type) X King (Upland type), Balls obtained a mean seed weight of 0.145 gram in the F_1 generation, while the mean seed weight of the Charara parent was 0.095 gram and of the King parent 0.085 gram. In the F_2 generation of the Afifi X Truitt hybrid, the mean seed weights ranged from 0.08 to 0.175 gram with two marked modes at 0.095 and 0.115 gram, respectively. The modal grouping in the second generation and the data from the third and fourth generations suggested to Balls that light seeds were segregating from heavy seeds in a ratio of 1:3.

In the F_2 generation of the Charara X King cross, where both parents were light seeded and close together in mean seed weight, the graph did not show as distinct modes as with the Afifi X Truitt hybrid. Instead of a 3:1 type of curve, as with the Afifi X Truitt F_2 population, the Charara X King second generation formed a more or less symmetrical curve ranging from 0.055 to 0.170 gram and lobed at 0.085, 0.105, 0.120, 0.140, and 0.150 gram. Through study by curve dissection, Balls observed some segregation in the Charara X King hybrids. He also noted an indication of segregation in the Sultani X Afifi cross in spite of the fact that the difference between the two parents was small.

Balls, in summarizing the evidence from his three crosses, states, "It would seem that beneath all the complexity involved by fluctuation, by autogeneous fluctuation, and by correlation, there existed in all these hybrids a straightforward segregation of seed-size, controlled by a single allelomorphic pair of factors in every case."

Balls did not report back crossing in his hybrids, however he carried his generations beyond the F_2. In detecting modes in quantitative inheritance or ratios in qualitative inheritance, back crossing is an easy and quick method of analysis. If modes or ratios exist at all, they should appear in sesqui-hybrids, particularly if they are from the back cross on the recessive parent. He did not call attention to the fact that intensification occurred in the F_1 generations of the inter-species crosses, but not in the first generation of the intra-species cross. Also, he did not discuss the persistence of hybrid vigor beyond the first generation in his Egyptian X Upland crosses. His F_2 graphs of these crosses show plants producing seed heavier

than the heaviest F_1 seeds and in the Charara X King hybrid practically half of the second generation population yielded seed heavier than the heaviest of the Charara parent. Second generation hybrid vigor persisted to a greater extent in the Charara X King cross than in the Afifi X Truitt cross. This is expected, however, since the parents were much nearer each other in the former cross than they were in the latter and since there was more segregation in the latter.

It is of interest to know whether hybrid vigor continues to be manifested or is dissipated in the increased fluctuation of the subsequent generations. The seed weight mean and the seed weight amount of fluctuation is shown for both way sesqui-hybrids and for the F_2 generation of the A, B, and C sets of crosses (Table 1 and Figs. 1, 2, and 3). The proximity of the allelomorphs (as heretofore referred to) for seed weight in the three crosses may be more of an advantage than a disadvantage in tracing the persistence of hybrid vigor in offspring beyond the conjugate generation (5). There is less chance of traces of intensification being confused with transmission of the mere grade of dominance. The less segregating out of lighter seeded plants, the more the level of the population mean is subtended.

The A crosses.—In the A crosses, the mean seed weight of the progeny from the back cross on the Winesap parental strain, of the progeny from the back cross on the Pima parental strain, and of the F_2 generation each was below that of the F_1 generation. The mean of the progeny from the back cross on the Winesap parental strain and the F_2 generation each was nearer that of the heavier seeded (Pima) parental strain than to that of the lighter seeded (Winesap) parental strain. However, the mean of the former population was lower than that of the latter populations, showing that the heavier dosage of the lighter seeded parental strain tended to lower the average seed weight in the sesqui-hybrid group below that of the F_2 generation. The mean of the progeny from the back cross on the heavier seeded (Pima) parental strain remained higher than that of the Pima parental strain itself. But this mean was lower than the F_1 mean. Hybrid vigor tended to dominate in the sesqui-hybrids, from the F_1 X Pima back cross, but it lost some of its force through the inclination of the population to segregate. The influence of dominance or hybrid vigor tended to hold up the means in the progeny from the back cross on the lighter seeded (Winesap) parental strain and in the F_2 generation, but these means were lowered by many of the plants fluctuating to lower seed weights. Hybrid vigor in many of the plants of the sesqui-hybrids and of the F_2 generations, however, did not wane. In all three of the populations,

after the conjugate generation, hybrid vigor in the plants as a group tended to dissipate in fluctuation.

Fluctuation was considerable in both sesqui-hybrid groups and in the F_2 generation. The wide dispersion in these populations is shown by their graphs in Fig. 1 and by their coefficients of variability in Table 1. No distinct modality was shown by the graphs, except in the population from the back cross on the Pima parental strain where the curve tended to be bimodal. This condition could not have been more than a case of oscillating fluctuations. The means and frequency distributions of the Pima parental strain and the F_1 plants were too nearly coincided to expect any segregation in the offspring of the F_1 X Pima back cross. The population from the back cross on the Winesap parental strain showed less variation than did the sesqui-hybrids from the F_1 X Pima back cross. The F_1 X Winesap back cross should have shown more variation than the F_1 X Pima back cross if the lighter seeds tend to segregate out. However, the wide expanse of fluctuation in the sesqui-hybrids and in the F_2 population, to points beyond the parental limits, indicates segregation, particularly since the F_1 population seemed less variable than either parental population. The curves of the sesqui-hybrids tend to show that the progeny from the back cross tend to move toward the mode of the parental strain with which the cross was made.

The B crosses.—In the B crosses, the mean seed weight of the progeny from the back cross on the Upright parental strain, the mean seed weight of the progeny from the back cross on the Pima parental strain, and the mean seed weight of the F_2 population were each below that of the F_1 generation, but they were approximately equal to or above that of the heavier seeded (Pima) parental strain in all three populations. The mean of the progeny from the back cross on the lighter seeded (Upright) parental strain was lower than the mean of the F_2 generation by reason of the fact that the former had an additional dosage of the lighter seeded parent. This sesqui-hybrid mean was practically equivalent to the mean of the heavier seeded (Pima) parental strain, and the F_2 mean was considerably above that of the heavier seeded parental mean. The mean of the progeny from the back cross on the heavier seeded (Pima) parental strain was much nearer to the F_1 mean than to the heavier seeded parental mean. The F_2 mean was also nearly halfway between the F_1 mean and the heavier seeded parental mean.

There was less fluctuation downward in the sesqui-hybrids and in the F_2 generation of the B crosses. Consequently, the means of these

populations were maintained relatively higher than they were in the A crosses. Hybrid vigor expressed as a mean of the three populations manifested itself in each of the three groups. With a tendency to segregate which seems to have taken place, mere dominance alone would not have maintained these means at the elevation at which they exist. The curve representing the population from the back cross on the Upright parental strain is more uniform than the curve representing the population from the back cross on the Pima parental strain. The deep incisions in the latter curve are due, no doubt, to violent fluctuations and not to modality. Each of these curves tends to follow the mode of the parental strain on which the back cross was made. The F_2 curve fulfilled the requirement for indicating segregation in that it extends beyond the two parental limits of deviation.

The C cross.—In the C cross, the mean seed weight of the progeny from the back cross on the Winesap parental strain and the mean seed weight of the F_2 generation were each lower than the mean seed weight of the F_1 generation, but the mean seed weight of the progeny from the back cross on the Sea Island parental strain was slightly higher than this F_1 mean seed weight. Thus, hybrid vigor, as expressed by the mean in the sesqui-hybrid group (from the back cross on the Sea Island), continued to be manifested. The mean of the progeny from the back cross on the lighter seeded (Winesap) parental strain was a shade higher than the mean of the larger seeded (Sea Island) parental strain. The mean of the F_2 generation was slightly above the midpoint between the two parental means. Hybrid vigor remained in both sesqui-hybrids. It waned somewhat in the progeny from one back cross on the lighter seeded (Winesap) parental strain and was somewhat intensified in the progeny of the back cross on the heavier seeded (Sea Island) parental strain. This difference, of course, is expected since there apparently was some segregation in the sesqui-hybrids and the mean seed weight of the Winesap parental strain was 2 grams lower than the mean seed weight of the Sea Island parental strain. There was much more segregation to lower seed weights in the F_2 population than in either sesqui-hybrid. Consequently, the mean of the F_2 population was lowered. The greater part of the F_2 plants coincided with the F_1 plants in seed weight, but there were several violent dispersions to very light seeds. The F_2 graph extended considerably beyond both parental limits.

The three sets of crosses.—In the three sets of crosses, hybrid vigor as expressed by the mean seed weight of the F_1 generation waned when expressed by the seed weight means of the sesqui-hybrids and F_2

generations, except in the case of the population from the back cross on the Sea Island where the mean seed weight was slightly, though not significantly, raised. The means in the generations that follow an intensified F_1 are expected to be lowered, because of the tendency of portions of the populations to fluctuate toward the parental forms. The graphs show this condition to be true for seed weight in all three sets of crosses. The graphs also show that a number of the plants in each of the populations remain as high in degree of hybrid vigor as many of those in the F_1 generation. Those plants that continue to intensify are probably the plants which are the more heterozygous for seed weight.

LINT INDEX

It has been shown heretofore that lint index was incompletely dominant in the A and B crosses and intensified in the C cross. However, since the variability in the Sea Island parental strain was very large and the fluctuation in the C cross F_1 was greater than in the other two F_1 populations, the intensification obtained may be an abnormal occurrence. The F_1 lint index as compared with the respective parental strains in the three sets of crosses is higher than that found by Kearney (3). This investigator in working with a Holdon X Pima cross reported the lint index mean of the Holdon (an Upland variety) as $5.8 \pm .14$, of the Pima as $4.70 \pm .06$, and of the F_1 as $4.8 \pm .03$. Low amount of lint was almost completely dominant, the mean of the F_1 being only $0.1 \pm .07$ higher than the Pima mean.

The lint index means and the lint index variability in the sesqui-hybrids and in the F_2 generation are discussed for each of the three sets of hybrids separately.

The A crosses.—In the A crosses, the lint index means of both sesqui-hybrids and of the F_2 generation are lower than the mean of the low lint index (Winesap) parental strain. The reduction of these means is only slight in the two sesqui-hybrid populations, but is more pronounced in the F_2 aggregation. Many of the plants in both sesqui-hybrids and in the F_2 fluctuated in lint index to a degree much lower than the lower limit of the lower (Winesap) parental strain. The frequency graphs (Fig. 4) indicate no distinct modality; however, these curves are notched and incised a great deal. The sesqui-hybrid curves are one superimposed upon the other practically. These two groups as a whole tend to shift toward lower lint index as compared with the F_1 lint index. The F_2 population shifted further in the lower direction. The bases of the curves of the three popu-

lations, however, extend from the upper limit of the higher parental strain or from beyond to points much lower than the lowest lint index in the lower parental strain.

The B crosses.—In the B crosses, the mean lint index of the progeny from the back cross on Upright, the slightly higher parental strain, is a shade higher than that of the slightly lower (Pima) parental strain, but the mean lint index of the progeny from the back cross on the Pima parental strain and the F_2 mean lint index are lower than the means of the lower (Pima) parental strain. The mean lint index of the progeny from the back cross on the Pima parental strain is slightly lower than the F_2 mean for this attribute. In the back cross progenies, the extra dosage of the Upright parental strain, on the one hand, tended to raise the mean and the extra dosage of the Pima parental strain, on the other hand, tended to lower the mean. This indicates that there was some tendency for higher lint index to be dominant in these sesqui-hybrids. As in the A crosses, many of the plants in both sesqui-hybrids and in the F_2 generation fluctuated in lint index to a degree much lower than the lower limit of the parental strains. The frequency curves (Fig. 5) show a wide dispersion for the two sesqui-hybrids and the F_2 populations. The fluctuation of the progeny from the back cross on the Pima parental strain extends to the upper limit of the higher (Upright) parental strain, while the other two populations each vary beyond this point. A larger percentage of the three populations taken as a whole deviate below the lower limit of the parental strains, however, than above.

The C cross.—In the C cross, the mean lint index of the progeny from the back cross on the higher (Winesap) parental strain is somewhat larger in weight than the mean lint index of the Winesap strain itself. The mean lint indexes of the progeny from the back cross on the lower (Sea Island) parental strain and of the F_2 generation are practically the same. These means are above the midpoint between the two parental means. In the C cross, the lint index means of the two sesqui-hybrid groups and of the F_2 generation maintained a higher position in respect to the parental strains than was the case with the A and B crosses. There was a higher degree of dominance for lint index in the F_1 generation of the C cross than there was in this generation of the other two sets of crosses.

As indicated heretofore, there was even a manifestation of hybrid vigor in the C cross. This extra hereditary strength in the conjugate generation seems to be evident in the following generations. The frequency graphs of the sesqui-hybrids are very irregular, but these curves do not show distinct modality. The F_2 curve has a wider

fluctuation than that of either sesqui-hybrid. However, the second generation curve is more regular in outline than those of the progenies from the back crosses. Only one plant in the F_2 generation deviated below the lower limit of the Sea Island parental strain. None of the plants in either sesqui-hybrid group fluctuated to a point as low as the lower limit of the Sea Island parental strain. Both sesqui-hybrid populations and the F_2 generation varied above the upper limit of the Winesap parental strain. The dispersion was greater beyond the upper parental limits than it was below the lower parental limits. This swing tended to be in the opposite direction for both of the sesqui-hybrid aggregations and the F_2 population in the A and B crosses.

VITIATING INFLUENCES

Some of the extreme fluctuations, particularly those to very low levels, may have been influenced by the nature of the genetical material itself. Kearney (3) reported low vitality for some of the F_2 plants in his inter-species (Holdon X Pima) cross. In hybrids of Egyptian and Upland or in hybrids of Sea Island and Upland a few plants occur in the segregating generations which are rather freakish in their characteristics. The normal production of such plants are affected or somewhat upset, especially in respect to fruiting and maturity. Poorly matured bolls have light seeds and a considerably reduced amount of lint.

SUMMARY

The data in this paper have been taken from three sets of crosses, *viz.*, the A crosses (Pima X Winesap), the B crosses (Pima X Upright), and the C cross (Winesap X Sea Island). These are three of the four sets of hybrids used in a previous study of lint percentage inheritance. In the former work, the first generation showed lowness of lint percentage to be intensified in the A crosses and completely dominant or slightly intensified in the B crosses. On the other hand, highness of lint percentage was incompletely dominant in the first generation of the C cross.

For the purpose of analyzing further the disagreeing features of lint percentage transmission as exhibited in the three sets of crosses, weights of 100 seeds and lint index determinations were taken from plants used in the A, B, and C sets of crosses of the former paper. As in the case with lint percentage, the study for seed weight and the study for lint index are carried through the two sesqui-hybrid generations and the F_2 generation of each of the three sets of crosses.

The relationship of the F_1 generation to its parental strains in seed weight and in lint index was compared with the relationship of the F_1 generation to its parental strains in lint percentage. This comparison was made for the three sets of hybrids. It is shown that the low degree of lint percentage in the first generation of the A and B crosses and the intergrade degree of lint percentage in the first generation of the C cross are resultants of intensified seed weight in these conjugate populations and not a definite status of lint amount. The percentage of lint was suppressed, not because of a decrease in lint yield, but by reason of the fact that the seed weight was increased through hybrid vigor. The more true or the more representative measure of lint yield, the weight of lint from 100 seeds, showed that the actual amount of lint in the F_1 generation was incompletely dominant in the A and B crosses and slightly intensified or fully dominant in the C cross.

A study of the variability of both parental strains and the F_1 generation in the three sets of crosses indicates that the parents of the A and B crosses were homozygous for seed weight as well as for lint index, but that the parentage of the C cross, particularly the Sea Island, was not genetically pure for either character. However, the Sea Island parental strain fluctuated much more for lint index than for seed weight. The other (Winesap) parental strain of the C cross also exhibited some more variation in lint index than in seed weight.

The F_1 seed weight results, likely, were not materially vitiated in the C cross, but whether or not the F_1 lint index mean of this cross is just above or just below the Winesap parental strain mean is problematical.

The contrasted allelomorphs for seed weight in each of the three sets of crosses were not widely removed from each other, neither were the opposing allelomorphs for lint index, in the three hybrid sets, remotely separated. The proximity of the antithetic character pairs for seed weight and also for lint index afforded little opportunity for segregation or for distinct modality in either character. The propinquity of the character pairs, on the other hand, provided good material for studying hybrid vigor transmission from the F_1 to generations beyond.

Lint index showed no hybrid vigor in the A and B crosses and very little if any in the C cross, consequently, the closeness of the allelomorphic members for this character serve no purpose in tracing the transmission of heterosis. However, with the C cross where lint index appeared to be intensified, the means of this character in the

sesqui-hybrid populations and in the F_2 population were subtended by some force not present in the A and B crosses.

Hybrid vigor as expressed in the seed weight persisted in many of the sesqui-hybrid and F_2 plants. The means of these generations occurred at a higher level than would have been maintained without heterosis. The wane in hybrid vigor, as expressed by the means of the sesqui-hybrid and F_2 groups, is attributable to segregation or the downward fluctuation of a portion of the plants in these generations. No distinct modality due to genetic behavior seemed to appear. However, variation was sufficiently wide to form a basis for concluding that segregation did occur.

In general, the three sets of crosses showed more variability in the lint index than they did in seed weight. In the parental strains, the coefficient of variability was higher for lint index than for seed weight, except with the Upright, where the reverse condition was true. However, the differences apparently were not significant, except in the Sea Island parental strain. The coefficient of variability in the F_1 generation was less for lint index than for seed weight, but the difference was not statistically reliable in the A and C crosses and barely so in the B crosses. The lint index was significantly more variable than the seed weight, according to the coefficient of variability, in all the sesqui-hybrid and F_2 populations, except in the F_2 generation of the C cross. In this last population the coefficient of variability was higher for lint index than for seed weight, but the difference was not much larger than the probable error.

In the sesqui-hybrids the mean of the seed weight tended to move toward the mean of the parental strain on which the back cross was made. The seed weight scatter was greater in these back cross progenies than in the parental strains, but the graphs bear out the fact that these sesqui-hybrids as a group were influenced by the parent upon which the F_1 was crossed and the population as a whole shifted in the direction of the parental strain of higher kinship.

With the lint index, there was less shifting of the sesqui-hybrids toward the parental strain upon which the back cross was made than there was with seed weight. According to the mean lint index, a slight movement occurred toward the parental strain in the B and C crosses and away from the parental strain in the A crosses, but the probable error showed little or no significance in the measure of the distance of the shifts. On the other hand, where the whole group is considered in the scatter graphs, there seems to be some tendency of movement of the sesqui-hybrid toward the parental strain involved in the back cross.

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QUANTITY DETERMINATIONS OF SEED FOR ROD ROWS OF SPRING OATS[1]

C. K. McCLELLAND[2]

When nursery rows for wheat are sown in spacings of 12 inches by 17.5 feet, 11 grams of seed per row equal 1 bushel per acre. When nursery rows of oats spaced 12 inches by 16.5 feet are sown, 11 grams of seed equal 2 bushels per acre. These lengths of row allow for the cutting off of the ends and the rates of seeding are sufficient when early seeding is practiced.

It is the common practice among agronomists to weigh the seed for each individual row prior to planting time and to have it in envelopes ready for use. With wheat, however, because of slight variation in size of seed, some have adopted the plan of measuring the seed for each row. A variation in number of seeds per row occurs whether the seed be weighed or measured, but the work of counting out equal numbers of seeds for each row is not to be considered. Since tillering is influenced by thickness of stand a reasonable variation in number of seeds per row is allowable. Even if the seeds are counted, differences would still exist because of slight differences in germination.

At the Arkansas Experiment Station where only soft red wheat is grown the measuring plan has been followed. Porcelain crucibles from the laboratories holding 16 cc of water will hold approximately 11 grams of wheat and this rate of planting is ample and in sufficiently

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Submitted with the approval of the Dean of Agriculture as Research Paper No. 229, Journal Series, University of Arkansas. Received for publication February 26, 1931.

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close agreement with all recommendations and practices. The work of planting is much reduced, though it must be said that only careful workmen can be employed to use the method.

With oats, there is more variation in the sizes of the seed, but the same fact holds good, *viz.*, that whether the seed be weighed or measured there is variation in the numbers of seed planted, this variation being much greater than in the case of wheat. Nevertheless, the work of counting the seed for individual rows is out of the question with large nursery plantings. The decision must be made between weighing or measuring and the majority favor the weighing method. A study of the relative merits of the two plans was undertaken at the Arkansas Experiment Station recently and the following report on these studies is given.

PRELIMINARY WORK

A porcelain crucible similar to the one used for wheat but holding 27 cc of water was used as a measure. Three types of spring oats, coarse, medium, and fine, were included. In determining the weights of these, 50 measures of each type gave the following averages, probable errors, and ranges:

Type of oats	Average weight per measure, grams	Range, grams
Fine	13.1±.048	12.0–14
Medium	13.2±.044	12.5–14
Coarse	12.6±.048	11.5–14

The measured oats showed close agreement in weight. The rate of seeding indicated is approximately 2.4 bushels per acre. The variation from 12.6 to 13.2 grams per measure amounts to a variation of approximately 3.5 pounds per acre in the seeding. It would seem then that the measuring of this seed should give as reliable results as the weighing.

Counts were then made of 24 measures of each and the average number of seeds with errors and ranges were found to be as follows:

Type of oats	Average number of seeds per measure	Range
Fine	754±2.8	707–790
Medium	584±3.7	538–636
Coarse	516±4.7	445–567

Lastly, counts were made on 10 varieties of spring oats (8 measures of each variety) and the following averages, errors, and ranges were obtained:

Variety	Average number of seeds per measure	Range
Fulghum	520±8.0	468–564
Elite	657±4.7	627–682
Canadian	671±2.8	657–692
Iowa 105	617±5.1	588–648
Iogold	643±4.8	612–669
Iogren	684±7.7	632–734
Nebraska 5	646±2.1	630–656
Nebraska 21	663±3.5	642–686
Nebraska 23	657±4.7	625–686
Kherson	646±6.5	612–699

The counts showed only a small and reasonable variation in the number of seeds in equal measures in each of these varieties. As between these varieties, also, negligible differences were found.

Tests were then planned to cover variations in rates of planting, and for a comparison of results with weighed, measured, and counted seed.

EXPERIMENTAL

RATE TEST

In order to find advantages, if any, of high or low rates, a range of planting of from 100 to 700 seeds per rod row was decided upon. Table 1 gives the planting plan and final results.

In the field planting, three rows of each variety were planted adjacent to the three rows of the other varieties planted at the same rate. The figures are averages of several rows as indicated. It is evident that for the coarse variety a rate of from 400 to 600 seeds per row is most satisfactory. If a suitable measure is available to supply these numbers its use should be perfectly satisfactory. The range of the counts of 5-gram samples exceeded 30 in only three or four instances so the variation in 11- to 14-gram samples should not exceed 100 seeds.

With the medium sized seed, rates of from 500 to 700 seeds were of about equal value. Since the crucible counts cover these numbers, the crucible measure should give satisfaction. The average number of seeds per 5-gram sample varies only 29 from that of the coarse oats, indicating less difference between the coarse and medium types than between the medium and fine, the difference between the latter averaging 86 seeds per 5-gram sample. This would indicate a number of from 200 to 300 seeds more per measure than from the medium and coarse seeds. These figures agree fairly well with those from the counts on the original seed given above in which the difference between fine and medium equalled 170 and that between fine and coarse equalled 238 seeds per measure.

TABLE 1.—*Results from various rates of rod-row plantings.*

Number of seeds planted	Average number of heads per row, aver. of 6	Average yield per rod row, aver. of 4	Average number of seeds per 5 grams, aver. of 8	Average weight per bushel, aver. of 8	Range of optimum rate
		X Oats (Coarse)			
100	247	165.8	203.5	30.2	
200	412	251.8	193.0	32.4	
300	443	264.8	215.0	31.0	400–600
400	495	300.3	197.8	31.5	
500	609	315.5	214.0	31.7	
600*	452	302.5	219.0	31.9	
700*	368	284.8	218.0	31.0	
Mean	432	269.4	208.0	31.4	
		Y Oats (Medium)			
100	245	267.5	261.0	28.8	
200	400	325.0	238.0	30.3	
300	436	292.8	231.5	30.9	
400	—	—	—	—	500–700
500	743	337.8	227.5	28.2	
600	870	337.5	232.0	27.9	
700	857	349.8	231.0	29.8	
Mean	592	318.4	237.0	29.3	
		Z Oats (Fine)			
100	162	212.5	328.5	30.0	
200	253	192.0	317.5	28.4	
300	265	158.0	317.0	30.9	
400	—	—	—	—	500–700
500	447	307.8	315.0	30.1	
600	464	287.5	329.5	30.8	
700	514	319.8	332.0	32.3	
Mean	351	246.3	323.0	30.4	

*By error the duplicate series had 200 or 300 in lieu of 600 or 700, but yields were not reduced.

METHOD OF DETERMINING AMOUNT OF SEED

Adjoining the test with various counts of seeds of the three varieties were some tests of another character scattered through which were various plats of Fulghum oats, the seed for which was counted, weighed, or measured. Table 2 summarizes the results of this test.

TABLE 2.—*Results from counted vs. weighed or measured seed.*

Method	Number plats, 3 rows each	Average number heads per row	Average yield, grams per row	Average number seeds per 5 grams
Counted, 400 seeds	16	488.4±19.7	267.3±19.5	199.0±3.1
Measured, 26–27 cc	11	479.0±21.7	315.0±24.3	203.0±5.7
Weighed, 11 grams	12	520.8±11.3	279.7±22.1	200.1±3.7

But slight difference in results was obtained. In number of heads per row, the measured seed showed the lowest number, but in grams per row the measured seed gave the highest yield. The difference in yield between measured and counted seed was 47.7 ± 31 and between measured and weighed 35.3 ± 33 grams, neither of which differences are significant when compared with their probable errors.

WEIGHED VS. MEASURED SEED OF SEVERAL VARIETIES

The third test was made with 10 different varieties in another location. Table 3 summarizes the results obtained.

The results were quite variable. Those obtained from the Fulghum checks were markedly different from those with Fulghum in the body of the test, i. e., in regard to number of heads per row. In regard to yield this difference did not show. With the Elite variety (*Avena sterilis*), the decrease in number of heads is apparently significant, but in none of the others is significance one way or the other shown. Substitution of the Fulghum check results or inclusion of these with the results from the test plats would give one significant difference of a plus nature. So far as number of heads are concerned, it might be said that there is little difference whether the seed be weighed or measured.

In regard to yields under the two methods, no significant differences exist except in the case of the Elite where yields were reduced when the seed was measured. As shown by the counts (given above), the number of seed per measure of Elite is not markedly different from that in the other varieties so this variation in results is inexplicable. As the difference in yields hinges on the difference in number of heads, a possible difference in tillering capacity seems the only explanation. However, the only conclusion can be, that, for these varieties, there is no difference whether the seed be weighed or measured.

SUMMARY AND CONCLUSIONS

1. Because of slight variation in size, seed wheat for rod rows can be as well measured as weighed. A porcelain crucible, 16-cc capacity, holds about 11 grams of seed which, planted in rows 12 inches by 17.5 feet, equals a rate of 1 bushel per acre.

2. Slight differences in rates result whether seed be counted, weighed, or measured. Counting seed for large scale operations becomes too laborious and, even if counted, variation in germination may occur.

TABLE 3.—*Results with weighed and counted seed of 10 varieties.*

Variety	Average number of heads per row, aver. of 9			Average number of grams per row, aver. of 9		
	Weighed	Measured	Difference	Weighed	Measured	Difference
Fulghum	328±10.7	319± 4.1	— 9±11.5	216±12.4	215± 3.8	— 1±12.9
Elite	520±15.0	415± 8.9	—69±17.4	298± 7.9	227±12.1	—71±14.5
Canadian	453±12.3	413±12.2	—40±17.3	184± 7.4	236±18.9	+52±20.3
Iowa 105	453±13.9	432± 7.8	—21±15.9	273± 9.9	260± 9.1	—13±13.4
Iogold	377± 9.6	411±14.9	+34±17.8	231±15.0	239±15.3	+ 8±21.4
Iogren	476±12.5	454±11.2	—22±16.8	245±16.9	239±10.5	— 6±19.8
Nebraska 5	484±15.5	467±15.2	—17±21.7	226±21.5	249±25.6	+23±33.4
Nebraska 21	498± 9.7	472± 9.8	—26±13.8	229±19.8	235±17.3	+ 6±26.3
Nebraska 23	500± 8.4	501± 6.3	+ 1±10.5	237±10.9	268±12.5	+31±16.6
Commercial Kherson	495± 8.7	461±10.1	—34±13.3	302±12.3	284±17.3	—18±21.2
Average of 10 varieties	458± 8.6	438± 6.1	—20±10.5	244± 6.5	245± 4.1	+ 1± 7.7
Average of 10 Fulghum checks		396± 9.3			215± 8.2	

3. Oats vary in size more than wheat and the preferable method of determining the amount of seed has been by weighing for each row. The present paper is a study of methods and a comparison of results when seed oats are counted, weighed, or measured.

4. In a comparison of weights of measured fine, medium, and coarse oats, the average weights respectively were found to be 13.1, 13.2, and 12.6 grams per measure (porcelain crucible 26- to 27-cc capacity). These weights are equivalent to about 2.4 bushels per acre, which is near the standard rate of seeding (10 pecks). Should a heavier rate be desirable a slightly larger crucible could be substituted.

5. Counts of these measured fine, medium, and coarse oats showed the average number per measure to be, respectively, 754, 584, and 516 seeds per measure. For oats as fine as 754 per measure, a smaller measure could be used, but the tests reported herein show little need of this substitution.

6. Similar counts on seeds of 10 varieties of spring oats showed only an allowable variation within a variety or even between the varieties. The extreme range in all was 468 to 734 seeds, but within a variety no range above 102 was found. The averages varied from 520 in Fulghum to 684 per measure in the Iogren variety.

7. In a test of rate of seeding of the fine, medium, and coarse seeded oats with from 100 to 700 seeds per row, the results showed that rates of 400 or more seeds per rod row gave the better yields. The number of heads per row was closely related to the number of grams per row, but neither one apparently was so closely correlated with the number of seeds used.

8. Results with counted (400), weighed (11 grams), and measured (26 to 27 cc) seeds of Fulghum oats showed a slight difference in favor of the measured oats which indicates perhaps that a slightly heavier rate than with the counts and weights used is desirable for this variety. In another test this difference was not found.

9. With 10 varieties, Fulghum included, no difference of note existed in number of heads per row or yield in grams per row as between methods of weighing or measuring the seed, except with the Elite variety, in which the measuring method gave the poorer results.

10. The conclusion can safely be drawn that for the varieties tested the seed may as well be measured as weighed. This being carefully done will lighten the work of nursery planting.

THE ROLE OF CHALK IN CALCAREOUS SOILS[1]

SURENDRALAL DAS[2]

Soils are generally designated as calcareous when the calcium carbonate exceeds about 10% and dominates all other constituents, controlling the soil properties. Very little work appears to have been done in the past to discover the specific function of chalk in calcareous soils, although a considerable amount of literature has accumulated from studies of lime-magnesia ratios required for normal growth of various crops in different types of soil or in solution cultures.

Gile (3),[3] while studying the relation of calcareous soils to pineapple chlorosis on certain areas in Porto Rico, concluded that the trouble was due to an excessive amount of chalk in the soils. This view is supported by Molz (5). Dauthenay (2) states that the occurrence of chlorosis on fruit trees in calcareous soils is quite common wherever for any reason nutritive elements of the soil become unassimilable to the tree. Chauzit's (1) analyses showed that vines suffered badly when 35% or more of chalk was present, but not when the amounts fell to 3%. The reason for these phenomena is not clear, but probably it is not due to any one factor.

On the other hand, Wyatt (6) showed that wheat, soybeans, alfalfa, and cowpeas grew normally either in 96% of dolomite and 4% of sand, in 100% of magnesian limestone, or in sand containing 7% of magnesite, and that dolomite up to 40% proved beneficial to plant growth. He therefore concluded that dolomite and magnesian limestone would not be detrimental as applied in agricultural practices.

To elucidate the effect of calcareous soils on the growth and ash composition of certain plants Gile and Ageton (4) grew eight species of plants, representing six families, e. g., rice, soybeans, bush beans, radishes, sunflowers, sweet cassava, sugarcane, and pineapple, in adjacent field plats containing 5, 18, and 35% of calcium carbonate. The plats were prepared by digging holes 20 feet long by 10 feet wide and 2 feet deep in a clay soil, leaving a bank 3 feet wide between plats. These were filled with clay, sand, and disintegrated limestone in proportions to furnish soils of the desired texture and composition.

The growth of bush beans and radishes was unaffected even by 35% of calcium carbonate; the growth of sunflowers, soybeans,

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[3]Reference by number is to "Literature Cited," p. 716.

and sugarcane was somewhat depressed by 18% and that of sweet cassava by 5% and markedly by 35%; and the growth of rice and pineapples was markedly depressed with the appearance of chlorosis by 5, 18, and 35% of calcium carbonate. The amounts of nitrogen, potash, and phosphoric acid were apparently unaffected by the carbonate, but the iron was notably depressed.

Such conflicting views as stated above regarding the rôle of chalk in calcareous soils led the writer to institute the present investigation with the object of throwing further light on this obscure phenomenon.

Soils in these parts of Bihar, India, belonging to the Gangetic alluvium, are highly calcareous, containing 30 to 40% of chalk. Notwithstanding this, these soils grow a variety of crops, such as wheat, paddy, maize, oats, barley, potatoes, different pulses and oil seeds, indigo, tobacco, sugarcane, etc.

In order to secure the advantages of the effect of chalk, only a small amount, say, 1 to 2%, generally suffices for the maintenance of favourable conditions of plant growth in a soil. It would appear of interest, therefore, to know in what manner the extra amount of chalk present functions in these calcareous soils and whether it stimulates or depresses plant growth.

The problem could be attacked in two different ways. First, the high proportion of chalk present in calcareous soils might be reduced by some treatment, and then in the soil residues thus obtained having different amounts of chalk crops could be grown to study its effect. Second, soil mixtures having different proportions of chalk could be made by adding different quantities of chalk to a soil with a small lime content, and then crops grown on these mixtures to study the function of chalk on their yield.

The first method would obviously require some acid treatment to obtain the desired soil residues with varying proportions of chalk, but the treatment is a drastic one as it will involve considerable depletion of plant food materials, such as potash, phosphoric acid, etc., along with the loss of chalk, and thus will materially affect the structure and constitution of the soil as a whole. The second method appeared to be a feasible one and was adopted for the purpose of this investigation.

Different proportions of powdered chalk were mixed in several groups of pots with a soil containing only 0.5% of calcium carbonate. A similar set of experiments was started in which nitrogen was added in the form of ammonium sulfate. The pots thus represented a series of soils with different calcium carbonate contents. A cereal crop

was grown on them. The pots were watered with clean well water throughout the experiment. As the plants matured and turned practically dead ripe, they were cut off close to the roots, air-dried, and weighed.

The soil used for these experiments was obtained in quantity from Kalianpur Experimental Station near Cawnpore in the United Provinces. It belongs to the Indo-Gangetic alluvium and is reported to be a fertile specimen. It is quite rich in available plant food, especially phosphoric acid (0.0776%), but is comparatively poor in organic matter and nitrogen (0.045%). It contains about 0.5% of chalk and has a pH of 8.17. The clay content (0.002 mm) is 14%.

Selected seeds of *Eleucine coracana* (Marwa, ragi), which had 98% germination capacity, were grown. The crop yield of individual pots is not given. Only the average results along with their probable errors are shown in Table 1, where each group included three pots receiving similar treatment except in the case of the 20% treatment in series 2 which had only two pots in the group.

TABLE 1.—*Average results of pot cultures to test the effect of chalk on cropping in Kalianpur soil.*

Chalk, %	Average yield of crops in grams		
	Grain	Straw	Total
	Series 1, With Nitrogen		
nil	24.0±0.5	62.4±0.6	86.4±1.5
5	26.2±0.5	68.1±2.1	94.3±1.7
10	27.8±0.6	67.4±0.5	95.2±0.3
15	28.2±0.9	67.5±1.3	95.7±0.7
20	32.0±0.7	75.1±0.1	107.1±0.6
	Series 2, Without Nitrogen		
nil	20.3±0.3	61.1±1.7	81.4±1.9
5	21.4±0.3	57.9±0.8	79.3±0.8
10	22.2±0.5	64.9±2.5	87.1±2.5
15	29.1±1.4	67.3±3.2	96.4±4.6
20	36.6±4.0	81.6±4.6	118.2±0.6

It will be noticed that the crops have responded to the treatment of chalk, though perhaps the increase in crop yield is not very great. On the other hand, a phenomenal increase is hardly to be expected as the soil is originally classed as fairly fertile.

Next it seemed desirable to consider the conditions that brought about increased crop yield with the addition of chalk. Results detailed above have indicated that the addition of chalk might have increased the available plant food in the several soil mixtures, or improved their physical condition.

In order to test which of these factors was more prominent, a series of pot experiments was started on the following lines. A portion of chalk was replaced by sand, which was used as a diluent of the soil and was expected eventually to improve its physical texture. The soil mixtures thus represented a series of calcareous soils with a definite amount of chalk, but having gradually increasing proportions of an inert substance like sand. Along with this, the previous year's experiments, with the exception of those with nitrogen added as manure, were repeated for confirmation.

Two series of experiments were instituted, e. g., series 1, with 0, 5, 10, 20, and 30% of chalk; and series 2, with 0, 5, 15, and 25% of sand, along with 5% of chalk in each group.

In series 2 a fixed amount of chalk was added throughout in order to maintain the calcareous character of the soil mixtures, for in the present investigation the author was only concerned with the behavior of the extra amount of chalk that is normally present in calcareous soils.

The crop used and methods followed were the same as in the previous year's experiments except in the case of the control and the 5% chalk which included four pots in each group. The results, along with their probable errors, are set forth in Tables 2 and 3.

TABLE 2.—*Average results of pot cultures to test the effect of chalk on cropping in Kalianpur soil, series 1.*

Chalk, %	Average yield of crops in grams		
	Grain	Straw	Total
nil	16.9±0.7	42.9±2.7	59.8±3.3
5	20.9±1.5	41.7±2.7	62.6±4.0
10	21.0±0.8	48.1±1.5	69.1±1.7
20	23.5±1.5	51.0±1.8	74.5±2.7
30	32.8±0.3	44.2±1.8	67.0±1.5

It will be found that the results obtained confirm those of the previous year, and therefore the same conclusion holds good as was obtained previously, e. g., the soil responds to the addition of chalk in an increased crop yield. However, it will be noticed that 30% of chalk tends to give a smaller yield than 20%, indicating that increased yield may be obtained by additions of chalk up to a certain limit only.

In Table 3 are given the results of pot experiments with sand carried out with a view to elucidate the effect of mechanical opening of the soil on crop growth. The sand was obtained from the bank of the Gandak, a tributory of the Ganges, and contained 5.7% of calcium carbonate, for which allowance was made in preparing soil

mixtures consisting of soil, sand, and chalk. There were three pots in each treatment, except the blank which included four pots.

TABLE 3.—*Average results of pot cultures to test the effect of sand on cropping in Kalianpur soil, series 2.*

Treatment		Average yield of crops in grams		
Chalk, %	Sand, %	Grain	Straw	Total
nil	nil	16.9±0.7	42.9±2.7	59.8±3.3
5	nil	16.5±1.1	48.2±2.3	64.6±2.7
5	5	23.2±2.6	55.2±4.5	78.4±7.1
5	15	17.4±0.5	51.6±3.8	69.0±4.2
5	25	18.6±1.0	42.3±1.8	60.9±2.1

It is evident that the addition of sand over 5% chalk added initially tends to improve the crop yield. It is noticed, however, that the increase in yield is not uniformly maintained as in the case of chalk (Table 1), and the maximum is reached with a smaller amount of sand than chalk. A probable explanation of this difference will appear from experiments reported below.

As the effect of sand could not be explained on chemical grounds, the cause of this similarity of behavior between chalk and sand must be sought in the probable change of the physical condition of the soil. In order to do this, the water-holding capacity of the several soil mixtures was determined. The results are set forth in Table 4.

TABLE 4.—*Effect of chalk or sand on the water-holding capacity of Kalianpur soil to which 5% chalk had been added to represent a calcareous soil.*

Kalianpur soil with 5% chalk + % of chalk or sand added	Water-holding capacity, %	
	With chalk	With sand
nil	52.04	——
5	50.32	49.53
10	49.82	48.36
15	49.05	47.37
25	48.38	45.95
Water-holding capacity of Kalianpur soil alone = 52.64%		

It is evident that the addition of either chalk or sand has lowered the water-holding capacity of the several soil mixtures, which are thus rendered more open and porous, and consequently the greater movement of air and water through them and better penetration of plant roots themselves are ensured, followed by a better fertility of the soil mixtures. Fig. 1 demonstrates the regularity in the falling off of the water-holding capacity of the soil under the above conditions. The graph denotes the soil mixture with 5% of chalk representing a calcareous soil.

That is to say, the addition of chalk to Kalianpur soil has conferred on it partly the character of a calcareous soil, especially with regard to its mechanical opening. Further, comparing the values of water-holding capacity obtained with the addition of sand and chalk (Table 4), it will be found that sand has lowered the water-holding capacity of the soil to a proportionately greater extent than has chalk (Fig. 1).

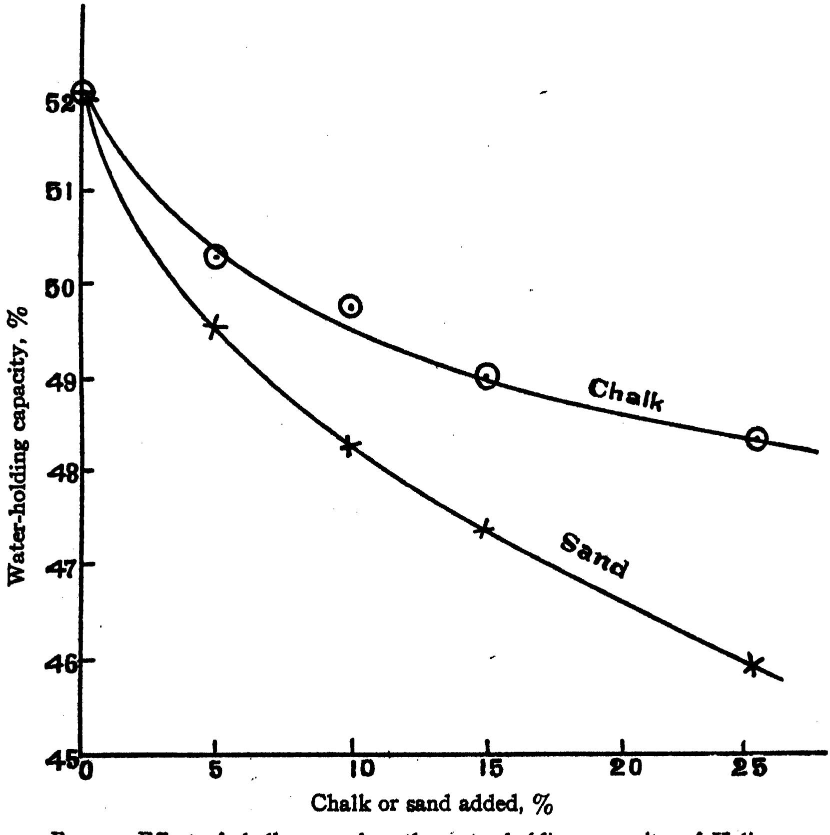

FIG. 1.—Effect of chalk or sand on the water-holding capacity of Kalianpur soil to which 5% chalk had been added.

On the other hand, the relationship between water-holding capacity and crop yields holds a certain degree of regularity which can be shown by plotting total yield against water-holding capacity of the several soil mixtures on which crops were grown (Tables 2, 3 and 4), as shown in Fig. 2.

It will be found that crop yield increases with decrease of water-holding capacity up to a certain limit, which is almost identical in character in both the series of soil mixtures consisting of either soil

and chalk, or of soil, chalk, and sand together. Beyond it, however, the further increase of either chalk or sand which lowers the water-holding capacity still more, decreases the crop yield. This is partly due to the fact that the incidence of too much aeration consequent

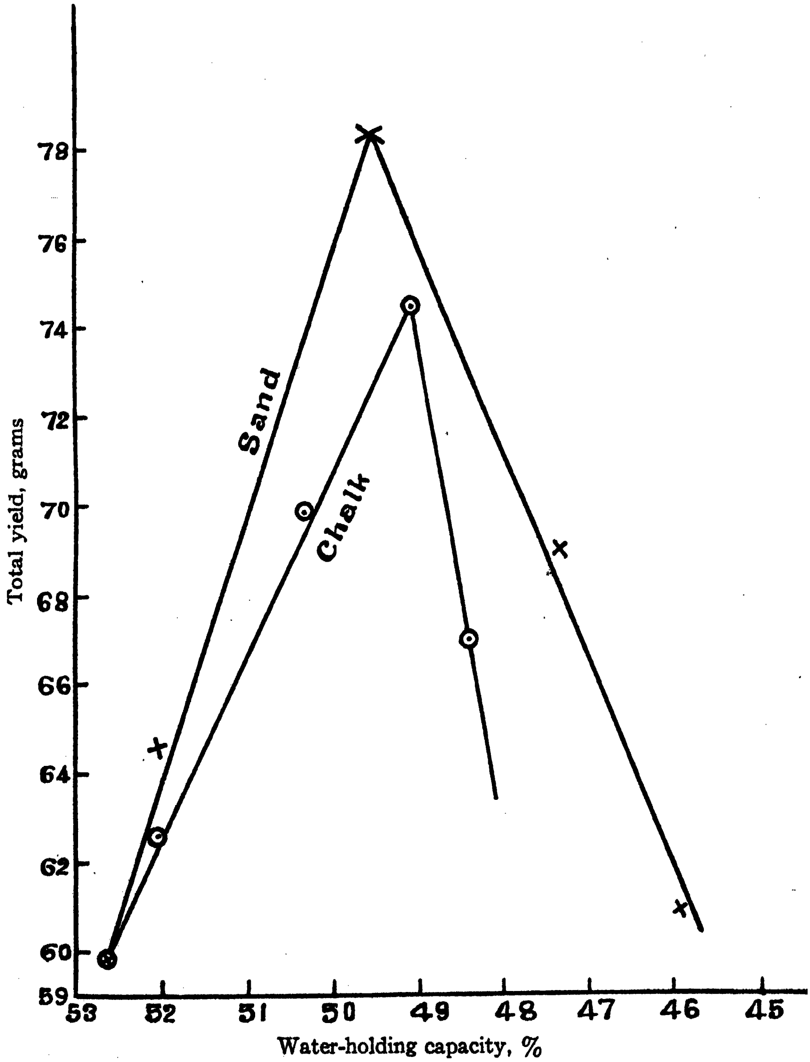

FIG. 2.—Relation between water-holding capacity and crop yield obtained with soil mixtures consisting of Kalianpur soil and chalk or sand.

upon the addition of an excessive amount of chalk or sand adversely affects the crop yield. Further, as the limiting value of water-holding capacity is reached much earlier with sand than chalk, the former shows a decrease in crop yield at a lower proportion than the latter.

SUMMARY

1. Pot experiments have shown that the presence of increasing proportions of chalk in a soil up to a certain limit tends to produce a better yield of crops.

2. When chalk is replaced by an inert substance like sand, a similar, though smaller, increase in crop yield is obtained.

3. This is attributed, among other factors, to an improved physical texture of the soil induced by mechanical opening.

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A PROBABLE CAUSE OF THE SMALL RESPONSE TO FERTILIZERS IN THE COTTON REGIONS OF ARMENIA[1]

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The results obtained from the use of mineral fertilizers in the cotton regions of Armenia are in full agreement with the experimental data of the last two to three years, *viz.*, that in some cases the cotton plant does not react satisfactorily to mineral fertilizers and therefore the cotton yields do not differ greatly from those of the unfertilized fields. The lack of positive results is sometimes a hindrance to popularizing the need for and the economic returns from the use of commercial fertilizers. The purpose of the work reported here was to attempt to determine the cause of the negative results obtained as revealed by the feeding process of the cotton plant.

The results of experiments with mineral fertilizers in the cotton districts of Armenia (Echmiadzin, Kourdoukuly), available for several consecutive years, show that the cotton plant is reacting

[1]Contribution from the Laboratory of the Department of Agriculture (Narkomsem) of Soviet Armenia, Erivan, Armenia. Received for publication February 5, 1931.

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sharply to nitrogenous fertilizers but phosphorus and potassium fertilizers separately give comparatively small increases in yield.

In order to analyze this question, we have selected an experiment with calcium cyanamid which generally gives positive results in the cotton districts of Armenia. The experiment is located in Echmiadzin where the soils have been formed under semi-desert conditions and due to a long period of cultivation and irrigation have acquired a considerable amount of organic matter, have increased their depth, and sometimes have improved structurally. These semi-desert soils are the dominant type of the cotton districts of Armenia.

Ten plats with identical soils and with similar conditions of cultivation have been studied with respect to the use of calcium cyanamid. The first two plats remained untreated as checks.

Mechanical analyses of the soils were made by the Robinson method. The organic matter was determined by the Knop method. Water extracts were prepared by shaking the soils for 5 minutes, the ratio of soil to water being as 1:5. In these extracts, all the elements were determined volumetrically. The replaceable bases in the soil were estimated by the Gedroiz (NH_4Cl solution) method. The methods of Dojarenko were used to determine some of the physical properties of soils. All calculations are made on a dry matter bases.

In Table 1 are given the mechanical analyses of the soils of the several plats.

It will be seen from Table 1 that the very fine sand to fine silt, inclusive, exceeded 75% of the soil mass, while clay occupied second place.

It is apparent that the plats do not differ materially in mechanical composition if we do not count the clay fractions where small differences are to be noted. The differences are especially noticeable in the lower soil layers which are perceptibly richer in clay particles washed down from above.

The organic matter in the arable layer of the soils fluctuates between 1.50–1.73% so that with respect to total humus content all of the plats appear quite uniform. Although the organic matter content is not high, it can be considered satisfactory for the semi-desert conditions that prevail. The highest percentage of humus appears in the arable layer with a decline in the lower soil layers. The water-soluble components of the soils are shown in Table 2.

The data in Table 2 show that all the plats are quite similar in soil composition, as well as in the vertical distribution of the soluble salts determined. Data on the replaceable bases found in the soils of these plats are given in Table 3.

It will be noted from Table 3 that the sum of replaceable calcium

TABLE 1.—*The mechanical analyses and amount of organic matter in the soils of the test plats.*

Plat No.	Depth in cm	Hygroscopic moisture, %	Total humus, %	Fine sand 1–0.25 mm, %	Very fine sand 0.25–0.05 mm, %	Silt 0.05–0.01mm, %	Fine silt 0.01–0.005 mm, %	Very fine silt 0.005–0.001 mm, %	Clay 0.001–mm, %
1	0–10	4.90	1.68	8.9	31.9	13.1	30.3	6.2	7.9
	15–25	5.02	1.39	8.1	31.7	11.3	31.1	7.7	8.7
	30–40	6.01	0.69	11.7	35.1	18.7	19.3	7.1	7.4
2	0–10	4.85	1.53	9.3	28.0	14.0	32.4	5.6	9.2
	15–25	5.00	1.34	10.0	29.0	8.4	33.1	8.2	10.0
	30–40	6.13	0.57	14.4	35.4	17.2	16.4	7.2	8.8
3	0–10	4.97	1.60	8.8	30.1	14.4	31.1	6.7	7.3
	15–25	5.00	1.37	8.6	31.3	11.2	29.7	7.4	10.3
	30–40	6.31	0.76	7.7	41.2	17.0	17.2	7.0	9.1
4	0–10	4.91	1.64	9.1	34.7	12.3	29.9	5.5	6.9
	15–25	5.12	1.40	8.3	31.6	10.3	30.1	9.1	9.2
	30–40	6.82	0.74	10.2	43.8	11.4	17.3	9.3	7.3
5	0–10	4.70	1.73	7.3	32.6	14.7	31.7	5.0	7.0
	15–25	5.27	1.43	10.5	27.1	13.0	31.3	8.3	8.4
	30–40	6.90	0.76	8.7	42.9	12.3	19.6	7.7	8.1
6	0–10	4.68	1.69	6.0	32.6	17.8	28.8	5.9	7.2
	15–25	4.99	1.32	12.4	27.3	11.6	28.4	10.8	8.2
	30–40	6.97	0.50	7.7	39.9	12.3	19.2	10.4	10.0
7	0–10	4.87	1.58	7.4	33.7	15.1	30.0	4.9	7.3
	15–25	4.98	1.30	12.0	27.5	14.1	28.1	9.4	7.6
	30–40	6.79	0.68	6.9	41.1	11.4	20.5	9.2	10.2
8	0–10	4.76	1.50	6.7	32.0	10.3	36.1	7.9	5.5
	15–25	4.77	1.27	11.3	27.9	15.7	29.0	8.8	6.0
	30–40	6.90	1.51	7.2	41.7	13.2	23.3	7.1	7.0
9	0–10	4.83	1.54	8.4	31.0	9.8	34.1	7.1	8.1
	15–25	4.18	1.25	10.0	25.2	16.4	27.1	11.2	8.9
	30–40	6.15	0.40	7.1	40.5	9.3	23.7	10.8	8.1
10	0–10	4.97	1.59	7.2	33.0	7.0	35.2	6.0	10.0
	15–25	5.00	1.34	8.6	21.2	20.5	28.8	9.4	10.2
	30–40	5.84	0.79	6.2	59.1	7.0	29.5	10.0	4.7

(with magnesium) in the upper arable layers fluctuates between 25 and 32 milligram equivalents in 100 grams of dry soil, a fairly close agreement. However, passing from the first two unfertilized plats which have the minimum replaceable calcium, it will be observed that replaceable calcium gradually increases in the direction of the last plat where it attains the maximum amount found. At the same time the replaceable sodium (with potassium), which in general is present in considerable quantity, shows the reverse with a comparatively large amount of replaceable sodium in the first fertilized

TABLE 2.—*Composition of water-extracts.*

Plat No.	Depth in cm	Dry matter in extract, %	Ash in extract, %	Loss on ignition, %	Total alkalinity, %	Cl, %	SO_3, %	CaO, %	MgO, %
1	0–10	0.0845	0.0648	0.0197	0.0277	0.0023	0.0019	0.0280	0.0012
	15–25	0.0698	0.0588	0.0160	0.0241	0.0027	0.0011	0.0124	0.0014
	30–40	0.0741	0.0646	0.0095	0.0251	0.0038	0.0020	0.0197	0.0009
2	0–10	0.0218	0.0701	0.0217	0.0284	0.0014	0.0022	0.0213	0.0009
	15–25	0.0753	0.0616	0.0137	0.0250	0.0021	0.0020	0.0188	0.0011
	30–40	0.0668	0.0556	0.0112	0.0193	0.0020	0.0023	0.0193	0.0013
3	0–10	0.0845	0.0600	0.0245	0.0290	0.0016	0.0017	0.0104	0.0004
	15–25	0.0778	0.0527	0.0251	0.0238	0.0013	0.0016	0.0122	0.0007
	30–40	0.0657	0.0497	0.0160	0.0206	0.0021	0.0020	0.0137	0.0007
4	0–10	0.0854	0.0640	0.0214	0.0304	0.0022	0.0020	0.0137	0.0001
	15–25	0.0798	0.0601	0.0197	0.0290	0.0028	0.0018	0.0120	0.0008
	30–40	0.0795	0.0632	0.0163	0.0254	0.0027	0.0017	0.0210	0.0012
5	0–10	0.0914	0.0640	0.0274	0.0287	0.0019	0.0022	0.0203	0.0008
	15–25	0.0853	0.0600	0.0253	0.0229	0.0024	0.0020	0.0199	0.0007
	30–40	0.0761	0.0551	0.0210	0.0200	0.0032	0.0019	0.0172	0.0010
6	0–10	0.0877	0.0663	0.0214	0.0274	0.0023	0.0023	0.0194	0.0009
	15–25	0.0761	0.0565	0.0196	0.0237	0.0020	0.0023	0.0172	0.0009
	30–40	0.0785	0.0610	0.0175	0.0240	0.0013	0.0030	0.0200	0.0013
7	0–10	0.0883	0.0690	0.0192	0.0291	0.0021	0.0020	0.0182	0.0011
	15–25	0.0838	0.0627	0.0211	0.0290	0.0021	0.0018	0.0182	0.0008
	30–40	0.0811	0.0643	0.0168	0.0254	0.0018	0.0027	0.0204	0.0014
8	0–10	0.0923	0.0680	0.0243	0.0294	0.0027	0.0019	0.0175	0.0013
	15–25	0.0875	0.0660	0.0215	0.0272	0.0029	0.0021	0.0192	0.0017
	30–40	0.0890	0.0700	0.0190	0.0277	0.0030	0.0032	0.0211	—
9	0–10	0.0874	0.0663	0.0211	0.0284	0.0026	0.0022	0.0201	0.0002
	15–25	0.0834	0.0660	0.0174	0.0280	0.0025	0.0021	0.0213	0.0009
	30–40	0.0841	0.0700	0.0141	0.0286	0.0031	0.0030	0.0227	0.0017
10	0–10	0.0972	0.0784	0.0188	0.0296	0.0020	0.0018	0.0300	0.0009
	15–25	0.0899	0.0720	0.0179	0.0290	0.0023	0.0023	0.0234	—
	30–40	0.0964	0.0794	0.0170	0.0293	0.0034	0.0039	0.0267	0.0003

TABLE 3.—*Amount of replaceable bases.*

Plat No.	Depth in cm	Total of replaceable bases	Milligram equivalents in 100 grams dry soil	
			Ca + Mg	Na + K
1	0–10	34.71	28.32	6.39
	15–25	24.65	18.17	6.48
	30–40	—	—	—
2	0–10	35.54	29.14	6.40
	15–25	26.76	20.08	6.68
	30–40	18.10	12.13	5.97
3	0–10	31.61	25.23	6.38
	15–25	28.08	20.14	7.94
	30–40	17.44	13.07	4.37
4	0–10	34.56	27.12	7.44
	15–25	30.54	22.27	8.27
	30–40	—	—	—
5	0–10	34.18	28.25	5.92
	15–25	28.16	21.17	6.99
	30–40	19.32	15.30	4.02
6	0–10	33.23	27.20	6.03
	15–25	24.46	18.17	6.29
	30–40	—	—	—
7	0–10	34.20	27.83	6.37
	15–25	24.34	17.39	6.35
	30–40	—	—	—
8	0–10	36.58	30.72	5.86
	15–25	28.17	22.17	6.00
	30–40	—	—	—
9	0–10	37.31	34.21	5.10
	15–25	27.50	22.13	5.39
	30–40	20.31	16.07	4.24
10	0–10	38.25	32.45	5.80
	15–25	26.14	20.14	6.00
	30–40	—	14.03	—

plat. The total replaceable bases fluctuate in much the same degree and approximately in the same direction as the replaceable calcium.

Thus a direct relationship can be observed between certain limits of replaceable calcium (with magnesium) as well as of sodium (with potassium) and the physical properties of these soils. This relationship is best shown by comparing the physical properties with cotton yields, as in Table 4.

Examining Table 4, it is not difficult to notice a sharp difference between plats in the capillary and non-capillary porosity of the soil, on one hand, and yield on the other. Taking the relation between the capillary and non-capillary porosity, we see that in plats 1, 2,

TABLE 4.—*The physical properties of the soils and cotton yields.*

Plat No.	Depth in cm	Absolute porosity of soil			Relative porosity of soil			Yields of cotton in centners per hectare*
		Capillary, %	Non-capillary, %	Total, %	Capillary, %	Non-capillary, %	Total, %	
1	0–10	37.0	3.8	40.8	90.7	9.3	100	
	15–25	37.4	3.8	41.2	90.8	9.2	100	
	30–40	37.8	3.9	41.7	90.7	9.3	100	6.7†
2	0–10	35.4	4.0	39.9	90.0	10.0	100	
	15–25	36.5	4.2	40.7	89.7	10.3	100	
	30–40	36.7	4.3	41.0	89.5	10.5	100	6.9
3	0–10	39.8	1.0	40.8	97.6	2.4	100	
	15–25	40.0	1.0	41.0	97.6	2.4	100	
	30–40	38.7	1.1	39.8	97.3	2.7	100	6.0
4	0–10	37.8	1.8	39.6	95.5	4.5	100	
	15–25	37.9	2.0	39.9	95.0	5.0	100	
	30–40	38.1	2.1	40.2	94.8	5.2	100	8.5
5	0–10	35.3	4.6	39.9	88.5	11.5	100	
	15–25	35.2	4.7	39.9	88.9	11.1	100	
	30–40	35.2	4.8	40.0	88.0	12.0	100	9.0
6	0–10	33.9	5.0	38.9	87.0	13.0	100	
	15–25	34.8	5.2	40.0	87.0	13.0	100	
	30–40	35.0	5.3	40.3	87.0	13.0	100	9.8
7	0–10	34.8	7.1	41.9	83.0	17.0	100	
	15–25	35.0	7.1	42.1	83.2	16.8	100	
	30–40	34.4	7.0	41.4	38.1	16.9	100	10.5
8	0–10	34.3	6.7	41.0	83.7	16.3	100	
	15–25	34.5	6.8	41.3	83.5	16.5	100	
	30–40	34.4	6.4	40.8	84.3	15.7	100	11.5
9	0–10	32.9	9.1	42.0	78.8	21.2	100	
	15–25	33.4	9.3	42.7	78.2	21.8	100	
	30–40	32.6	9.5	42.1	77.5	22.5	100	13.0
10	0–10	31.9	9.9	41.8	76.3	23.7	100	
	15–25	32.0	10.0	42.0	76.2	23.8	100	
	30–40	32.3	9.8	42.1	76.7	23.3	100	14.5

*1 centner = 100 kg. (220 lbs.); 1 hectare = 2.47 acres. †About 590 lbs. per acre.

3, and 4 the non-capillary porosity comprises less than 10% of the total porosity, which is a very unfavorable condition, especially in plats 3 and 4 where the percentages reach the lowest limit. On plat 10 the non-capillary porosity attains almost 24% accompanied by the maximum yield.

Comparing the yield data, we find a marked, correlation with non-capillary porosity. The correlation between yield and physical properties of these soils is further illustrated in Fig. 1.

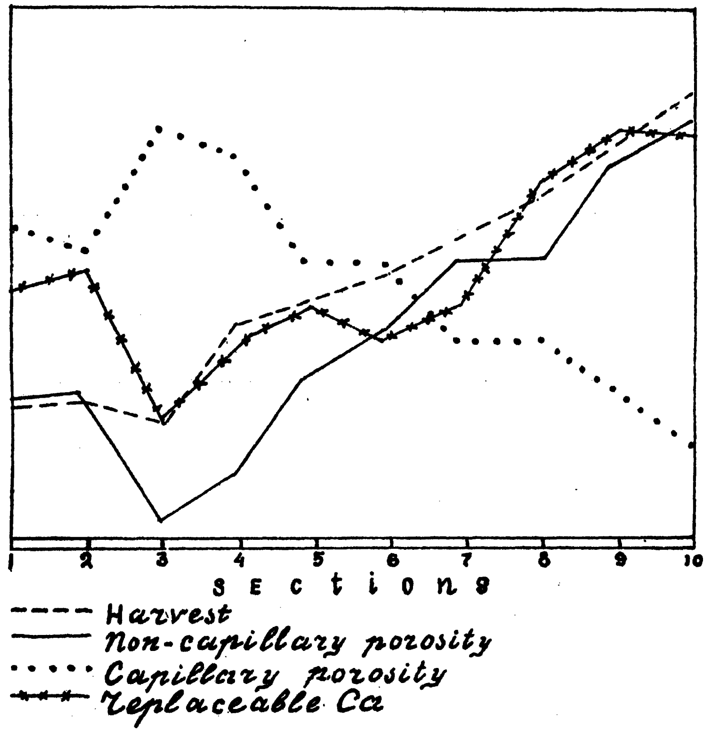

FIG. 1.—Correlation of yield of cotton with the physical properties of the soil.

It will be observed that yield is correlated with an increase in non-capillary porosity, as well as with an increase in replaceable calcium which usually leads to an improvement in the physical properties of soils.

These findings lead to the tentative conclusion that the cause of the small response of these soils to fertilizer applications is not due to the fertilizing material itself, but to the unfavorable physical condition of the soils which suppresses the normal feeding process of the cotton plant.

For maximum yields of cotton where fertilizers are used it is necessary to give serious attention to the improvement of the physical properties of these soils.

NITROGEN BALANCE IN A FOUR-YEAR GRAIN ROTATION, 1881 TO 1921[1]

J. W. WHITE and F. J. HOLBEN[2]

Since 1881, nitrate of soda applied biennially to corn and wheat has been compared with various other manurial treatments in the old field plat experiments of the Pennsylvania Agricultural Experiment Station. In addition to the nitrate treatment these plats receive also a uniform dressing of superphosphate and muriate of potash. A study of these plat soils compared with those that receive similar applications of phosphorus and potassium fertilizers affords an opportunity for determining the ultimate fate of the applied nitrogen and its residual effect upon the soil in addition to its economic value in the production of the several crops included in the rotation.

PENNSYLVANIA FIELD PLAT EXPERIMENTS

The Pennsylvania soil fertility experiments of the old fertilizer series include 144 one-eighth acre plats arranged in four tiers of 36 plats each. The 23 manurial treatments, with the exception of burnt lime, are applied to corn and wheat in a 4-year rotation of corn, oats, wheat, and hay (mixed clover and timothy). The burnt lime treatment is applied once each rotation to the corn ground. During the first 10 rotations (1881 to 1921) no lime was applied except to plats in which it is included in the scheme of treatments. In 1922 and 1923, all plats of tiers two and four, respectively, with the exception of two PK-treated plats and those previously limed, received a dressing of pulverized limestone. With the exception of the plats which receive farm manure, the only source of organic matter has been the roots and stubbles of the harvested crops. The experiments are located on a residual limestone soil of the Hagerstown series. The soil at the beginning of the experiments was very productive as shown by the early yields of the untreated plats. Prior to the establishment of the plats the land was used for general farming and from 1867 to 1881 various miscellaneous experiments were conducted, including variety tests and tillage experiments.

[1]Paper read as part of the program of the Soil Fertility Conference held at Pennsylvania State College, State College, Pa., June 24–26, 1931, commemorating the fiftieth anniversary of the soil fertility plats. Publication authorized by the Director of the Station as technical paper No. 533. Received for publication July 13, 1931.

[2]Professor and Assistant Professor of Soil Technology, respectively.

PLAN AND SCOPE OF PRESENT STUDY

The present study deals with the first 40 years of the experiments during which time the original plan was carried out without change. Six plats are included in the study as follows:

Plat No.	Treatment applied per acre biennially
24	Unfertilized
25, 29	PK, 48 pounds P_2O_5+100 pounds K_2O
26	PK+24 pounds N in $NaNO_3$
27	PK+48 pounds N in $NaNO_3$
28	PK+72 pounds N in $NaNO_3$

The data presented are gained from a study of these six plats during several different periods of the experiment, namely, 1881 to 1921, 1881 to 1899, 1899 to 1910, and 1910 to 1921.

The nitrogen removed in crops is based on the average composition of crops as reported by Thorne (1)[3]. These data agree very closely with the figures secured by Pingree (2) and MacIntire (3) who analyzed the oats and wheat crops grown on a number of the Pennsylvania field plats. Since there are no figures available on the composition of the corn and hay from these plats, it was thought advisable to use the figures of Dr. Thorne for each of the four crops.

On the basis of our present knowledge, two-thirds of the nitrogen in the clover plant is derived from the air and one-third from the soil. Two-thirds of the nitrogen in the plant is contained in the harvested crop. The removal of the clover hay therefore does not change the nitrogen relation of the soil. In consideration of this fact the actual nitrogen removed in the harvested clover hay is not included in that computed as removed from the soil. Only the timothy hay, therefore, is included in the nitrogen removed by the hay crops. Field notes kept by C. F. Noll (4) of the relative proportions of clover and timothy are used as the basis of estimating the timothy hay harvested.

The balance sheet used for measuring the nitrogen inventory of the soil is that suggested by Russell (5) and shows clearly the gain and loss of nitrogen during the first 40 years of the experiment. The soil is credited with the annual addition of 5 pounds of nitrogen per acre derived from rain and snow and also an average annual addition of 1.15 pounds per acre added in seeds. The pounds of nitrogen per acre applied in nitrate of soda during the 40 years under study were as follows: Plat 26, 480; plat 27, 960; and a plat 28, 1440.

[3]Reference by number is to "Literature Cited," p. 739.

RELATION OF RESIDUAL SOIL NITROGEN TO YIELDS OF AIR-DRY MATTER

Earlier studies on these plats (6, 7, 8) have shown that there exists a close correlation between the soil organic matter and the yields of crops on similarly treated plats. Since the nitrogen content of the soil organic matter remains constant, it is obvious that a constant ratio should exist between the air-dry matter produced and the residual soil nitrogen. As stated earlier, the only source of organic matter on these plats is the roots and stubble and these should be returned to the soil in proportion to the respective yields of harvested crops.

If the total air-dry matter produced during a definite period on a particular plat is divided by the total nitrogen in pounds per acre found in the soil at that time, a fairly constant ratio is found to exist. This ratio varies with each different treatment which is in accordance with the yield and organic matter ratio previously established (8). The ratios of the plat soils included in the present study, based on the pounds per acre of nitrogen present in the soil in 1921 divided into the total air-dry matter produced during the last rotation and, in case of the check plat, using the average yields of the last two rotations, were as follows:

	Plat 24	Plats 25, 29	Plat 26	Plat 27	Plat 28
Ratio	3.81	5.87	6.79	7.17	7.30

The plats which have received nitrogen show a wider ratio, as would be expected, since nitrogen is known to stimulate the decay of organic matter. The constancy of the ratio may be shown from the ratio on the untreated plats from 1899 to 1931, which represents the extreme periods of nitrogen determinations on the plats under study, as follows: 1899—3.73; 1907—3.98; 1908—3.82; 1909—3.91;1910—3.86; 1911—3.76; 1915—3.70; 1921—3.81; 1931—3.78; average, 3.81.

SIGNIFICANCE OF THE NITROGEN-YIELDS RATIO

The discovery of this relationship which the senior author has recently found to exist makes it possible to estimate the nitrogen content of the soil at definite periods of the experiment. The earliest nitrogen studies were made in 1899 by Hess (9). There is no record of the original nitrogen content of the plat soils at the beginning of the experiment. Since this ratio has remained constant for a period of 32 years on the untreated soils, it seems logical that such a ratio existed on these plats at the beginning of the experiment. Therefore, if the yields of air-dry matter produced during the first rotation on the untreated plats are divided by the factor 3.81, the approximate

nitrogen content of the soil may be determined. By computing the assumed yields of the untreated plats, the original nitrogen content of each plat is estimated.

As will be shown by later data, there occurred a rapid loss of nitrogen during the first four rotations, at the end of which time the various plats approach a state of equilibrium. Fortunately, the data of Hess (9) were secured about the time the soils approached this period of the experiment. These data, together with those secured by Brown and MacIntire (10), make it possible to compare the actual nitrogen found with that computed from the nitrogen-yields ratio. Table 1 shows the data secured in relation to several differently treated plat soils. In case of each differently treated plat, the computed nitrogen is obtained by dividing the yields of air-dry matter by the factor established for each respective treatment.

The data of Table 1 show that there exists a close correlation between the actual nitrogen of the plat soils found by analysis and that computed by means of the nitrogen-yields ratio. In fact, the

TABLE 1.—*Relation of computed nitrogen to that actually found at different periods of the experiment expressed as nitrogen percentages.*

Date sampled	Actual %	Computed %	Difference %
	PK+72 Lbs. N in $NaNO_3$		
1899	0.1378	0.1401	+0.0023
1908	0.1228	0.1182	—0.0046
1910	0.1255	0.1291	+0.0036
1931	0.1393	0.1332	—0.0061
	Lime and Manure		
1899	0.1468	0.1444	—0.0024
1910	0.1454	0.1511	+0.0057
1911	0.1589	0.1546	—0.0043
1915	0.1510	0.1495	—0.0015
1928	0.1820	0.1850	+0.0030
	Lime Alone		
1899	0.1199	0.1170	—0.0029
1909	0.1160	0.1147	—0.0013
1911	0.1194	0.1148	—0.0046
1928	0.1245	0.1276	+0.0031
	Untreated Plats		
1899	0.1244	0.1223	—0.0021
1907	0.1129	0.1161	+0.0032
1908	0.1036	0.1042	+0.0006
1909	0.1120	0.1135	+0.0015
1910	0.1102	0.1136	+0.0034
1911	0.1122	0.1110	—0.0012
1915	0.1150	0.1120	—0.0030
1931	0.1115	0.1108	—0.0007
Average	0.1281	0.1277	—0.0004

average difference in case of the two methods is equivalent to only 8 pounds per acre. These data indicate that the differences of most of the determinations are within the limits of nitrogen determinations, taking into consideration the errors involved in soil sampling, preparation of sample, and laboratory analysis.

The authors do not wish to give the impression that this method of computing nitrogen is applicable to a wide range of conditions. Only in case of long-time continuous treatments will such a method be of value. In fact, with the exception of the untreated plat soils, it is doubtful if this ratio method could be applied to these plats during the early stage of the experiment before the soils had reached a stage of equilibrium. Since this year marks the fiftieth anniversary of these plats and since several 1931 samples are included in Table 1, the senior author shall designate this new discovery as the Golden Key Method, for he believes it will unlock many of the secrets held by these plat soils concerning the ultimate fate and residual effects of applied nitrogen.

In the tables to follow, concerning the nitrogen balance, the nitrogen figures, with the exception of those determined by analysis in 1921, will be those computed by the method described.

ECONOMIC VALUE OF THE SEVERAL NITROGEN APPLICATIONS

The data concerning the economic value of the plat treatments have already been published (11) and need not be discussed in detail at this time. It is of interest in relation to the data to follow to note that the three rates of nitrogen application have maintained the yields for 40 years, while the PK treatments of plats 25 and 29 are beginning to show a decline in yields, due no doubt to the invasion of soil acidity. The untreated plat shows a decline of approximately 50% on the basis of the first and tenth rotations. Fig. 1 shows the trend of the three treatments during the first 40 years of the experiment.

ACIDITY OF PLAT SOILS

Since the maintenance of nitrogen on the PK and untreated soils is dependent primarily upon the activity of the nitrogen-fixing micro-organisms, the data dealing with the invasion of soil acidity are of utmost importance. Information available on the subject shows that the activity of azotobacter is dependent upon a soil reaction approaching that of neutrality. The limits of activity appear to be between pH 6 and 7. The nitrogen fixation organisms, including the anaerobic clostridium group, however, have a wider range of

activity (12), *viz.*, between pH 5.7 and 6.9. Table 2 shows the lime requirement of the plats made in 1910 by Gardner and Brown (13) and also the lime requirement data secured in 1921. Table 3 shows the pH values secured on the 1921 samples.

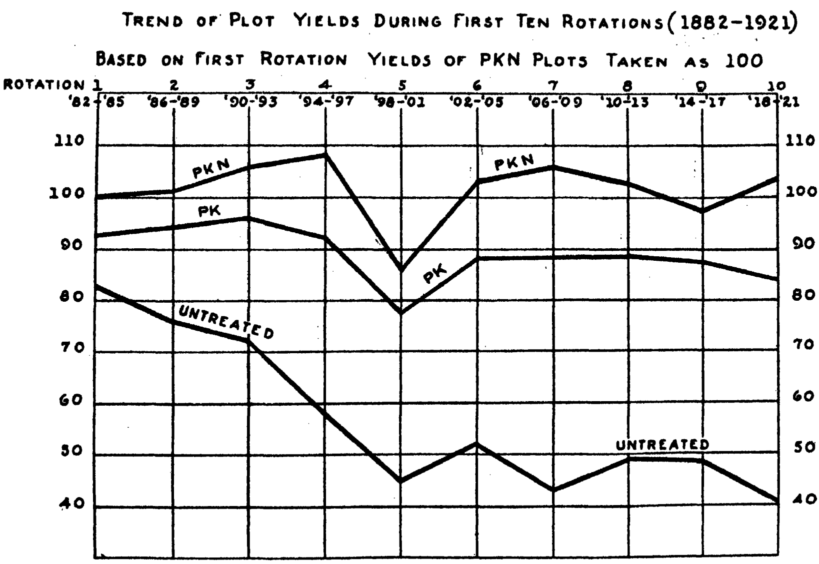

FIG. 1.

TABLE 2.—*Lime requirement of plat soils in 1910 and 1921.**

Tier No. and year	Plat 24, untreated	Plat 25, PK	Plat 26, PK+24N	Plat 27, PK+48N	Plat 28, PK+72N	Plat 29, PK
1—1910.....	610	813	545	614	407	1,152
1—1921.....	2,019	2,560	2,038	1,801	2,133	2,351
2—1910.....	neutral	neutral	neutral	neutral	neutral	neutral
2—1921.....	76	237	521	1,138	1,090	872
3—1910.....	575	1,120	1,017	954	1,030	1,118
3—1921.....	1,355	2,180	2,019	2,133	1,706	1,943
4—1910.....	620	870	1,830	1,530	1,300	1,320
4—1921.....	948	1,972	2,018	2,133	2,322	2,162
Average						
1910......	451	701	848	775	684	897
1921......	1,100	1,737	1,649	1,801	1,810	1,832
Increase, 11 years...	649	1,036	801	1,026	1,126	935
Annual increase.....	59	94	73	93	102	85

*Reported in terms of pounds per acre of $CaCO_3$.

TABLE 3.—*pH values of 1921 plat soils.**

Tier No.	Plat 24	Plat 25	Plat 26	Plat 27	Plat 28	Plat 29
1..........	5.54	5.42	5.64	5.56	5.51	5.22
2..........	6.40	6.32	6.26	5.71	5.81	5.96
3..........	5.47	5.51	5.41	5.36	5.54	5.22
4..........	5.74	5.56	5.56	5.49	5.54	5.51
Composite of 4 tiers....	5.73	5.66	5.70	5.46	5.54	5.46

*pH determinations made by C. D. Jeffries.

The data included in Tables 2 and 3 are of special interest in relation to the maintenance of nitrogen on those plats which are dependent upon the activity of micro-organisms for the major supply of nitrogen. With the exception of the soils of tier 2, the invasion of acidity has no doubt become a limiting factor for nitrogen fixation. The pH values are for the most part beyond the limit for the activity of azotobacter. Even in case of the more tolerant anaerobic micro-organisms, such as those of the clostridium group, the pH values have reached the danger point. On tiers 1 and 3, therefore, which are to be continued without the addition of lime, the yields of crops will no doubt rapidly decrease with soil nitrogen as the limiting factor. It is of interest to note that the plat soils which have received nitrate of soda show no tendency toward reduced acidity as has been the claim of many investigators. The lime requirement figures bear a very close relation to the pH values as a measure of soil acidity.

NITROGEN FIXATION STUDIES

Preliminary studies made by the "Plaque Method" failed to show the presence of azotobacter colonies on any of the six plats under study. Even with the addition of lime, phosphorus, and both starch and mannite, there were no developments of azotobacter colonies. In similar studies, however, made on the plats of the series which have received limestone since the beginning of the experiment, there were developed typical colonies of azotobacter. In each of the tests made, there was developed a strong odor of butyric acid which suggests that on these acid soils the fixation of nitrogen is due to the activity of anaerobic micro-organisms of the clostridium group (12). Studies of a more definite nature concerning nitrogen fixation of these plats are now in progress. It seems important, however, in connection with the nitrogen balance studies to point out the results of the preliminary studies which throw some light on the maintenance of soil nitrogen on certain of the plats under consideration.

NITROGEN IN SOIL AT END OF 40 YEARS

As the result of the relationship found to exist between the residual soil nitrogen and the dry matter produced at definite periods of the experiment, it becomes possible to determine the approximate loss of nitrogen at several different periods between 1881 and 1921. These studies reveal the fate of the applied nitrogen and throw new light on the cause of differences in yield relations existing between the several plats selected for the present study. Table 4 shows the pounds per acre of nitrogen found by analysis on each of the four tiers of plats at the end of 40 years.

TABLE 4.—*Total nitrogen in pounds per acre found in the surface soil at the end of 40 years.**

Tier No.	Plat 24, untreated	Plat 25, PK	Plat 26, PK+24N	Plat 27, PK+48N	Plat 28, PK+72N	Plat 29, PK
1	2,366	3,005	3,075	2,830	2,870	2,610
2	2,060	2,601	2,485	2,470	2,564	2,570
3	1,916	2,615	2,490	2,450	2,470	2,285
4	2,270	2,660	2,660	2,765	2,770	2,965
Average	2,153	2,720	2,678	2,629	2,669	2,608

*Based on 2,000,000 pounds soil.

RESIDUAL EFFECT OF APPLIED NITROGEN

The PK- and PKN-treated soils show almost identical nitrogen content at the end of 40 years of continuous cropping. This is an interesting fact when it is realized that plat 28, for instance, has received a total of 1,440 pounds of applied nitrogen. The average difference between this plat and the PK treatment is only 5 pounds in favor of the nitrate-treated soil. These data bear out the observation of Russel (5) to the effect that the nitrogen content of the soil is not dependent upon the nitrogen applied but to the presence of organic carbon. The nitrogen applied will influence the maintenance of soil nitrogen only by its effect in bringing about increased yields of crops resulting in the return of more crop residues. This factor, however, is largely overcome by the residual effect of the applied nitrogen in causing excessive decay of the crop residues returned to the soil. It is of interest in this connection to show the relation (Table 5) of yields of air-dry matter (a measure of the crop residues returned to the soil) to the maintenance of soil nitrogen of the several plats under consideration. This relationship brings out clearly the destructive effect of the applied nitrogen in bringing about excessive decay of soil organic matter.

TABLE 5.—*Residual soil nitrogen in relation to crop yields, with the check (plat 24) as 100.*

	Plat 24	Plats 25, 29	Plat 26	Plat 27	Plat 28
Soil nitrogen	100	123	124	122	124
Average yields	100	156	173	179	182
Yields last rotation	100	208	241	250	259

These data show that the nitrate of soda plats have received 78% more crop residues than the untreated soil and have maintained a soil nitrogen content of only 23% in excess of that soil. In relation to the PK treatment, the nitrate of soda treated soils have received 22% more crop residues and have maintained the same nitrogen content. The residual effect of the nitrate of soda in relation to organic matter decay may be further emphasized by a comparison of the ratio of soil nitrogen to yields of crops or return of crop residues. In other words, if the soil nitrogen maintained on the PK and PKN plats bore the same ratio to yields as that of the unfertilized soil, the nitrogen content of these soils would be as follows:

	Plats 25, 29	Plat 26	Plat 27	Plat 28
Ratio same as check	3,365	3,733	3,859	3,927
Actual nitrogen, 1921	2,664	2,678	2,629	2,669
Difference	701	1,055	1,230	1,258
Excess over PK	—	354	529	557
Equivalent to pounds of soil organic matter	—	7,869	11,669	12,466

The above figures show that although the nitrate of soda treated plats have maintained the yields for 40 years, the actual maintenance of nitrogen has been greatly reduced. The difference between the PK and PKN treatments shows the effect of the applied nitrogen on the decay of soil organic matter. The N-C ratio of these soils found at the end of 40 years is as follows:

	Plat 24	Plats 25, 29	Plat 26	Plat 27	Plat 28
N-C ratio	13.48	13.20	12.85	12.81	12.96

The PKN plats show a somewhat narrower ratio than the PK treatment.

NITROGEN BALANCE AT FOUR PERIODS OF THE EXPERIMENT

Tables 6, 7, 8, and 9 show the relative rate of nitrogen loss in relation to that applied and removed in crops.

TABLE 6.—*Losses of nitrogen from plat soils during first 40 years, 1881 to 1921, in pounds per acre.*

	Plat 24, untreated	Plats 25, 29, PK	Plat 26 PK+24N	Plat 27 PK+48N	Plat 28 PK+72N
Nitrogen in soil in 1881*	3,998	3,963	3,974	3,962	3,950
Nitrogen added in seed, rain, and fertilizers	246	246	726	1,206	1,686
Nitrogen expected in 1921	4,244	4,209	4,700	5,168	5,636
Nitrogen found in 1921	2,153	2,664	2,678	2,629	2,669
Nitrogen loss from soil	2,091	1,545	2,022	2,539	2,967
Nitrogen removed in crops	962	1,440	1,635	1,683	1,706
Nitrogen balance, gain (+) or dead loss (—)	—1,129	—105	—387	—856	—1,261
Annual gain (+) or loss (—)	—28.2	—2.6	—9.7	—21.4	—31.5

*Computed from the nitrogen-yields ratio.

The data in Table 5 show that in case of each of the soils there occurred a loss of nitrogen during the 40 years of the experiment in excess of that removed in crops.

TABLE 7.—*Losses of nitrogen during the first 18 years, 1881 to 1899 in pounds per acre.*

	Plat 24, untreated	Plat 25, 29, PK	Plat 26, PK+24N	Plat 27, PK+48N	Plat 28, PK+72N
Nitrogen in soil in 1881*	3,998	3,963	3,974	3,962	3,950
Nitrogen added in seed, rain, and fertilizers	111	111	327	543	759
Nitrogen expected in 1899	4,109	4,074	4,301	4,505	4,709
Nitrogen found in 1899*	2,503	2,858	2,815	2,763	2,811
Nitrogen loss from soil	1,606	1,216	1,486	1,742	1,898
Nitrogen removed in crops	528	670	746	757	766
Nitrogen balance, gain (+) or dead loss (—)	—1,078	—546	—740	—985	—1,132
Annual gain (+) or loss (—)	—59.9	—30.3	—41.1	—54.7	—62.9

*Computed from the nitrogen-yields ratio.

The PK-treated plats show a loss considerably less than that of the other plats. The nitrogen lost from the PKN plats in excess of that of the PK treatments gives a measure of the fate of the nitrogen applied in nitrate of soda. Such a comparison shows that 58.8% of the nitrogen applied on plat 26 was lost from the soil, compared to 78.2 and 80.3%, respectively, on plats 27 and 28. The actual pounds per acre of nitrogen lost in excess of PK are 282, 751, and 1,156, respectively. The nitrogen lost from the untreated soil exceeds that of all the plats, except that of plat 28. The yield of air-dry matter on the untreated soil during the last rotation is 50% less than that produced during the first rotation (11). During this period the untreated soil suffered a total loss of soil nitrogen equivalent to 1,845 pounds per acre.

TABLE 8.—*Losses of nitrogen from 1899 to 1910, in pounds per acre.*

	Plat 24, untreated	Plats 25, 29, PK	Plat 26, PK+24N	Plat 27, PK+48N	Plat 28, PK+72N
Nitrogen in soil, 1899*	2,503	2,858	2,815	2,763	2,811
Nitrogen added in seed, rain, and fertilizers	67	67	200	332	463
Nitrogen expected in 1910	2,570	2,925	3,015	3,095	3,274
Nitrogen found in 1910*	2,290	2,769	2,692	2,716	2,688
Nitrogen loss from soil	280	156	323	379	586
Nitrogen removed in crops	219	385	443	467	470
Nitrogen balance, gain (+) or dead loss (—)	—61	+229	+120	+ 88	—116
Annual gain (+) or loss (—)	—5.5	+20.8	+10.9	+8	—10.5

*Computed from the nitrogen-yields ratio.

This loss is equivalent to 46% of that present in the soil in 1881. These data show that the loss of nitrogen is parallel to the reduction in yields. On the PK plats the total soil nitrogen lost is equivalent to 1,299 pounds per acre, or 33%, of that originally present. At the same time, the reduction in yields of air-dry matter between the first and last rotation is only 4%. Based on an average of the three plats, the nitrate of soda treatments lost in 40 years 1,303 pounds of soil nitrogen, equivalent to 33% of that originally present. The yield of air-dry matter during the last rotation, however, is 1.4% in excess of that produced during the first rotation.

As stated earlier, at the beginning of the experiment these soils were in a high state of productivity. Each plat soil readjusted itself

TABLE 9.—*Losses of nitrogen from 1910 to 1921, in pounds per acre.*

	Plat 24, untreated	Plats 25, 29, PK	Plat 26, PK+24N	Plat 27, PK+48N	Plat 28, PK+72N
Nitrogen in soil in 1910*	2,290	2,769	2,692	2,716	2,688
Nitrogen added in seed, rain, and fertilizers	67	67	200	332	463
Nitrogen expected in 1921	2,357	2,836	2,892	3,048	3,151
Nitrogen found in 1921	2,153	2,664	2,678	2,629	2,669
Nitrogen loss from soil	204	172	214	419	482
Nitrogen removed in crops	215	385	446	459	470
Nitrogen balance, gain (+) or dead loss (—)	+11	+213	+232	+40	—12
Annual gain (+) or loss (—)	+1.0	+19.3	+21.1	+3.6	—1.1

*Computed from the nitrogen-yields ratio.

to the changes brought about by the new cropping system and manurial treatments instituted. Apparently the readjustment took place for the most part during the first four rotations as shown from the data included in Table 7. From 1881 to 1899, a period of 18 years, there occurred a total loss of soil nitrogen equivalent to 81% of that lost during the 40 years in case of the check plat, 85% from the PK treatment, 89% from plat 26, 90% from plat 27, and 88% from plat 28.

During the period from 1899 to 1910 (Table 8), the plat soils approached a state of equilibrium. With the exception of the untreated soil and that of plat 28, the nitrogen removed in crops exceeds that lost from the soil. The untreated soil shows during this period an annual loss of nitrogen in excess of that removed in crops equivalent to only 5.5 pounds per acre compared to 59.9 pounds lost annually during the first 18 years of the experiment. In like manner, the annual loss from plat 28 was reduced from 62.9 pounds to 10.5 pounds per acre. In other words, the fixation of atmospheric nitrogen during this period has more than kept pace with that lost from the soil with the two exceptions noted.

During the period from 1910 to 1921 (Table 9), the final equilibrium was reached. The soil of plat 28 is the only one that shows an annual loss of nitrogen in excess of that removed in crops, equivalent to only 1.1 pounds per acre, which could hardly be taken as a significant difference. On each of the other plat soils the nitrogen removed in crops is in excess of that lost from the soil. The fixation of nitrogen

during the last half of the experiment accounts for the gain in nitrogen over that lost from the soil.

The loss of soil nitrogen, as shown from the preceding tables, parallels the data secured at the New Jersey Station as reported by Lipman and Blair (14) in their cylinder experiments. In this experiment, the nitrogen content of the soil at the beginning of the experiment was almost identical with that computed in case of the Pennsylvania soils. It is of interest, therefore, to compare the loss of soil nitrogen in the two experiments. The following data show the changes that took place in the Pennsylvania soil during a period of 40 years and in the New Jersey soil during a period of 20 years.

Pennsylvania Soil (Plat 28)		New Jersey Soil (Cylinder 8A)	
Nitrogen %	Pounds per acre	Nitrogen %	Pounds per acre
0.1968	3,936	0.1975	3,950
0.1452	2,904	0.1406	2,811
0.1323	2,646	0.1344	2,688
0.1279	2,558	0.1335	2,669

The New Jersey soil lost during the first 10 years 74.9% of the total soil nitrogen lost during the 20 years of the experiment. The Pennsylvania soil lost during the first 18 years 88% of the residual soil nitrogen lost during 40 years. The annual loss of soil nitrogen in case of the New Jersey experiment, based on that shown by soil analysis, was 68.9 pounds, as compared to 32 pounds per acre from the Pennsylvania experiment.

The loss of nitrogen from the Pennsylvania soils, as shown by the balance sheets included in Tables 6 and 7, no doubt includes both that removed from the soil by drainage and that lost as gaseous nitrogen as discussed by Lyon (15). In the 4-year grain rotation followed in the Pennsylvania experiment there is a period of 33 months from the time wheat is seeded until the developed sod is plowed for corn. During this period the presence of nitrate nitrogen is reduced to a minimum, due to the fact that the growing plants utilize the soluble nitrogen and also because the soil micro-organisms assimilate nitric nitrogen during the process of breaking down the dead roots which have a wide N-C ratio. The first two months after seeding oats, and during the months of May, June, and July of the corn year, are the periods during which the maximum nitrogen is lost by drainage, as suggested by the field studies of Brown and MacIntire (10). After the corn harvest and until the ground becomes frozen in late November, and during the early spring before the corn

stubble is plowed for oats, occur several months during which some nitric nitrogen is lost.

As stated in the plan and scope of the present paper, the nitrogen removed in the clover hay is not included in that removed in crops. On the basis of our present knowledge, the clover plant leaves behind approximately the same amount of nitrogen as that removed in the harvested crop. The soil, therefore, does not suffer a loss of nitrogen attending the removal of the clover hay. There are those no doubt who believe that the soil inventory or balance sheet should include the total nitrogen removal in all crops. It is of interest to show, therefore, the nitrogen balance both including and excluding the clover nitrogen. Such a comparison is shown in Table 10.

TABLE 10.—*Annual gain (+)* or loss (—)* of soil nitrogen during the several periods of the experiment.*

	Plat 24, untreated		Plats 25, 29, PK		Plat 26, PK+24N		Plat 27, PK+48N		Plat 28, PK+72N	
	A†	B	A	B	A	B	A	B	A	B
1881–1921	—22.3	—28.2	+ 9.1	— 2.6	+ 4.0	— 9.7	— 9.9	—21.4	—20.1	—31.5
1881–1899	—53.2	—59.9	—18.3	—30.3	—24.9	—41.1	—42.7	—54.7	—57.8	—62.9
1899–1910	— 0.7	— 5.5	+32.8	+20.8	+24.9	+10.9	+20.0	+ 8.0	+ 0.4	—10.5
1910–1921	+ 6.1	+ 1.0	+30.5	+19.3	+33.8	+21.1	+13.9	+ 3.6	+11.4	— 1.1

*In excess of that removed in crops.
†A, including the nitrogen removed in clover hay; B, excluding the clover nitrogen.

From a comparison of the above data it is evident that when the soil is credited with the nitrogen removed in the clover hay the loss is considerably less. In case of the PK plats, by including the clover hay nitrogen, the soil shows an annual gain of 9.1 pounds of nitrogen in excess of that removed in crops based on the 40 years of the experiment. The loss of nitrogen on the PKN plats in excess of the PK treatment, however, leaves approximately the same relation in case of both A and B. That is, on plat 26, 42.5% of the nitrogen applied in nitrate of soda is unaccounted for, as compared to 79.1% for plat 27 and 81.1% in case of plat 28.

SUMMARY

Six plats are included in the present study including a representative of the untreated series, PK treatment, and three plat soils which have received nitrate of soda in three rates of application, namely, 24, 48, and 72 pounds of nitrogen applied biennially to corn and

wheat. The study includes the first 40 years of the experiment during which time 480, 960, and 1,440 pounds, respectively, of nitrate nitrogen have been applied.

The nitrogen balance studies are based on the following periods of the experiment: 1881–1921, 1881–1899, 1899–1910, and 1910–1921. A study of the available data covering these periods shows that there exists a definite relation between the crop residues returned, as measured by crop yields, and the nitrogen content of the soil. If the dry matter produced at a definite time is divided by the pounds per acre of soil nitrogen found during that period, a fairly constant ratio is established. Thus, on the untreated soil, this ratio from 1899 to 1931 was found to be as follows: 1 pound of nitrogen equals 3.73, 3.98, 3.82, 3.91, 3.86, 3.76, 3.70, 3.81, and 3.78 pounds of air-dry matter. The average ratios for the different plat soils were as follows: Untreated, 3.81; PK, 5.87; 24 N, 6.79; 48 N, 7.17; and 72 N, 7.30. Therefore, if the pounds of air-dry matter produced at periods since 1899 (the first sampling period) are divided by the factor of the respective plats, the pounds per acre of soil nitrogen are closely estimated. Thus, in case of nine periods, including four widely different treatments (Table 1), the average computed soil nitrogen was found to be 2,554 pounds compared to 2,562 found by analysis. This discovery is used in estimating the nitrogen content of the soil during several periods selected for study.

The effect of nitrate of soda on soil reaction is shown from the following data representing the accumulative effect of 40 years:

	Plat 24, untreated	Plat 25, PK	Plat 29, PK	Plat 26, PK+ 24N	Plat 27, PK+ 48N	Plat 28, PK+ 72N
Lime requirement	1,100	1,737	1,832	1,649	1,801	1,810
pH............	5.73	5.66	5.46	5.70	5.46	5.54

Contrary to the general belief, nitrate of soda when used with PK has shown no tendency to reduce soil acidity. There is found to be a close correlation between the lime requirement and pH of these soils.

Preliminary studies indicate that the non-symbiotic fixation of nitrogen on these acid soils is carried out by the clostridium group rather than by azotobacter.

The nitrogen content of the three plat soils (at the end of 40 years) which have received nitrate of soda was found to be, on an average, 2,659 pounds as compared to 2,664 pounds for the PK treatment. The heavy applications of nitrate of soda have had no effect on increased maintenance of soil nitrogen.

NPK treatment has caused an average yield of crops 78% in excess of the untreated soil, the soil nitrogen maintenance, however, being only 23% above the untreated soil. Although nitrate of soda has maintained a yield of 22% in excess of PK, the nitrogen content of the soil is slightly less. If the nitrogen content of the nitrate of soda plats bore the same ratio to yields as the untreated soil, the soil nitrogen would be 3,840 pounds instead of 2,659 pounds. The residual effect of the nitric nitrogen on the decay of soil organic matter is thus shown.

During the first 18 years of the experiment, there occurred a rapid loss of nitrogen in case of each plat soil. The nitrogen lost from the soil, excluding that removed in crops, amounted to over 71% of the total lost in 40 years. The annual gain (+) or loss (—) of nitrogen during the several periods of the experiment in excess of that removed in crops* is as follows:

	Plat 24, untreated	Plats 25, 29, PK	Plat 26 PK+24N	Plat 27, PK+48N	Plat 28, PK+72N
1881–1921	—28.2	— 2.6	— 9.7	—21.4	—31.5
1881–1899	—59.9	—30.3	—41.1	—54.7	—62.9
1899–1910	— 5.5	+20.8	+10.9	+ 8.0	—10.5
1910–1921	+ 1.0	+19.3	+21.1	+ 3.6	—1.1

*Not including nitrogen removed in clover hay.

The excessive loss of nitrogen during the early period of the experiment, during which time each individual plat soil was undergoing a readjustment in accordance with the respective manurial treatment, is in accordance with results obtained at the New Jersey Station and at Rothamsted. The tendency of the plat soils to reach a state of equilibrium is clearly shown from the above summary. Nitrogen fixation is playing an important rôle as shown by the fact that during the latter periods the nitrogen removed in crops exceeds that lost from the soil.

Of the total nitrogen applied in nitrate of soda, 58.8% was lost from the soil in case of plat 26, 78.2% from plat 27, and 80.3% from plat 28. (Nitrogen lost in excess of the PK treatment.)

CONCLUSIONS

In a 4-year grain rotation, on a fertile soil, the accumulations of nitrogen during the period of sod, brought about by non-symbiotic fixation, together with that supplied by the clover roots, is sufficient to meet the normal demands of the grain crops. This is true only when lime, phosphorus, and potassium are liberally supplied. Thus in 40 years the application of 1,440 pounds of nitrogen on plat 28 has

resulted in a total increased yield of only 62 bushels of corn, 16 bushels of oats, 68 bushels of wheat, and 1,400 pounds of hay in excess of the PK treatment. This is true in spite of the fact that no lime was used during the 40-year period. The fact that nitrogen is not a serious limiting factor in such a rotation is further emphasized when it is realized that a total of 1,440 pounds of nitric nitrogen applied during the 10 rotations has caused total increased yields of only 12 bushels of corn, 3 bushels of oats, 27 bushels of wheat, and 70 pounds of hay in excess of an application of 480 pounds of nitrogen applied to plat 26.

The results of a supplementary phosphate experiment (16) suggest that heavier applications of superphosphate on the PK and PKN treatments would have brought about a somewhat higher level of crop yields which, in turn, would have resulted in a more economic utilization of the applied nitrogen.

It is true, however, that the major limiting factor for crop production is that of moisture distribution during the growing season rather than the lack of plant food. Thus, in 1928, when ample rain fell during the summer months, plat 28 produced 82.7 bushels of corn compared to an average annual yield of 58.3 bushels.

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SEEDLING COLOR AND YIELD OF SUGAR BEETS[1]

S. B. NUCKOLS[2]

INTRODUCTION

The common commercial varieties of sugar beets show varying percentages of individuals with a definite red pigmentation, the remainder being of a yellow shade and without red color. The color is most noticeable in the hypocotyl of young seedlings and in the small leaf buds in the crown of mature beets. Similar observations have been previously made by various workers (1, 2, 3).[3] The red coloration ranges from a carmine red to light shades of pink and the yellow coloration varies from deep orange to light shades which appear almost white. In this work the separations attempted have been into a class called red and into a class called yellow which includes the rest of the plants of varying degrees of color from strong yellow to a complete absence of pigment. In the standard varieties of sugar beets the red or yellow color is not found in the flesh of the root. The epidermal cells of the leaves of sugar beets do not show pronounced color, but mangels and various horticultural varieties show strong leaf color in the seedling stage. Leaf petioles usually show more color than leaf blades.

In young sugar-beet seedlings of the common commercial varieties the variations in color of the hypocotyl are very noticeable at thinning time. The full range of variation in colors is found in almost all

[1]Contribution from Office of Sugar Plants, Bureau of Plant Industry, U. S. Dept. of Agriculture, Scottsbluff, Nebr. Received for publication March 6, 1931.

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[3]Reference by number is to "Literature Cited," p. 743.

varieties. The above condition suggested the study of these varied seedlings to determine whether color of seedlings had any direct correlation upon weight of root or sugar content of beet at harvest time. No separation was attempted on the basis of the degree of intensity of the two colors used. Jurbin (4) claims that the degree of color shown by the leaf buds is significantly negatively correlated with sugar content.

If such a correlation should exist there should be no great difficulty in selecting or breeding for the more desirable color. A further study was made to determine whether the color as shown in the hypocotyl of the young beet was the same as that shown in the leaf buds of the mature beet grown from the young seedling.

EXPERIMENTAL DATA

During the growing season of 1926 a commercial field of sugar beets was selected and 1,000 red seedlings and 1,000 yellow seedlings thinned so as to have two types of seedlings in separate plats. At harvest each beet was carefully examined for the occurrence of color in the leaf buds by slicing through the central crown bud with a sharp topping knife. In all of these beets the color of the crown bud and other leaf buds was found to correspond with the color shown by the hypocotyl of the young seedling from which the beet grew.

Tests were made of commercial strains of sugar beets to determine if there was a correlation between color of the seedlings and the yield. In one commercial field a few rows of beets were harvested and by examination of the leaf buds they were sorted into two classes depending on red or yellow color production. There were 303 red and 235 yellow beets in this area. The average weight of the red class was 16.8 ounces as contrasted with an average weight of 14.4 ounces for the yellow class. This weight difference is not believed significant. As will be seen in the following tests of somewhat different nature, less difference in yield between these two color classes of beets was shown.

In a field planted with a standard commercial variety, the following plats were laid out: Twenty beet rows, 50 feet long, were thinned so that only red seedlings remained and 20 alternate beet rows of the same length were thinned so that only yellow seedlings remained. These plats received the same treatment throughout the season.

The results are shown in Table 1. It will be seen that there is no significant difference in the average sugar content or in the yield per acre. No relation of color to sugar percentage or to yield could be found.

In another experiment in which 37 different strains of sugar beets were grown in 1/100-acre plats replicated seven times, an exact count was made of the percentages of red and of yellow seedlings found in each variety. These counts were made before the plats were thinned. The plats were then commercially thinned without reference to the color of seedlings. The percentages for the two color types, red and yellow, at harvest should be approximately the same as

TABLE 1.—*Sugar beet yields from red or yellow seedlings.*

Plat No.	Yield of beets per acre in tons		Percentage sugar in beets		Gross sugar per acre in pounds	
	Red	Yellow	Red	Yellow	Red	Yellow
1......	12.95	12.83	17.4	17.7	4,506.6	4,541.8
2......	11.52	14.49	15.2	17.0	3,502.1	4,926.6
3......	15.56	10.33	16.3	16.7	5,072.6	3,450.2
4......	12.00	14.61	17.2	16.4	4,128.0	4,792.1
5......	12.35	9.22	16.0	17.5	3,952.0	3,227.0
6......	10.69	10.45	16.1	16.5	3,442.2	3,448.5
7......	10.81	14.25	16.6	16.5	3,588.9	4,702.5
8......	10.22	13.30	17.5	15.7	3,577.0	4,176.2
9......	10.81	12.12	17.4	16.7	3,761.9	4,048.1
10......	12.71	9.03	16.7	16.3	4,245.1	2,943.8
11......	11.05	11.40	17.2	16.2	3,801.2	3,693.6
12......	10.10	15.20	15.8	15.3	3,191.6	4,651.2
13......	8.20	11.40	16.9	16.1	2,771.6	3,670.8
14......	11.40	9.15	17.9	17.4	4,081.2	3,184.2
15......	15.92	9.27	18.0	17.6	5,731.2	3,263.0
16......	16.04	11.44	17.4	17.7	5,581.9	4,049.8
17......	13.07	15.00	16.3	16.7	4,260.8	5,010.0
18......	12.63	12.77	15.2	16.4	3,839.5	4,188.6
19......	13.41	8.91	17.2	17.0	4,613.0	3,029.4
20......	12.63	18.57	16.1	16.5	4,066.9	6,128.1
Average	12.20 ±.310	12.19 ±.404	16.7 ±.13	16.7 ±.10	4,085.8 ±115.0	4,056.3 ±127.6

TABLE 2.—*Comparative yields from 37 varieties of sugar beets classified according to their variation in color of seedlings.*

Percentage of yellow seedlings	Average percentage of yellow seedlings	Number of varieties in group	Yield per acre in tons	Percentage sugar in beets	Gross sugar per acre in pounds
1 to 10	4.25	10	13.25±0.31	18.51±0.15	4,908.3±122.0
11 to 20	14.46	11	13.17±0.72	18.81±0.16	4,965.2±145.9
21 to 30	24.17	6	13.30±0.24	18.73±0.21	4,978.7±243.6
31 to 40	34.80	4	14.11±0.51	18.65±0.27	5,266.3±301.1
41 to 50	44.80	4	13.00±0.50	18.15±0.33	4,718.6±143.5
51 to 60	53.50	2	12.06±0.43	17.65±0.25	4,256.5± 79.3
over 61	0.00	0	0.00±0.00	0.00±0.00	0.0± 0.0
Average of 37 varieties	20.85	—	13.24±0.13	18.56±0.08	4,919.6±58.0

determined by the pre-thinning count. The results of this test (Table 2) show variation in the yields from the different groups of plats, but the differences are inconsistent and show no significant trend related to the color of seedlings.

SUMMARY

All sugar beets carry some color pigment of either red or yellow color. This color is most distinct in the hypocotyl of the small plants during the first four weeks of growth. It is also readily discernible in the small leaf buds of the mature plants.

The color of the young hypocotyl and the mature leaf buds is the same, therefore selection for this character may be made during any stage of growth of the plant.

Color of plant does not seem to be correlated with either yield or sugar content in the varieties studied.

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EFFECTS OF IRRIGATION AND ALFALFA PRODUCTION ON ARID SOIL COMPOSITION[1]

T. J. DUNNEWALD[2]

Arid soils are reputedly low in organic matter as compared with humid soils because of the more sparse vegetation and the warm dry conditions which favor rapid oxidation of the organic matter. When such land is watered artificially, the effect upon the soil is that of a complete change of climate. Vegetative growth is greatly stimulated and more roots and organic material are incorporated with the soil. The alternate drying and moistening of the soil greatly stimulate biological activity and the production of available plant food, while penetration of large amounts of water should be expected to carry soluble materials and colloids from the surface downward.

A series of soil samples was collected in the Saratoga Valley in southern Wyoming during a survey of the soils for a proposed extended irrigation project in the valley. The samples consisted of composite borings of the A and B horizons of soil from seven of the oldest alfalfa fields which could be found in the valley. These fields had been constantly in irrigated alfalfa for from 12 to 35 years, with an occasional reseeding in some cases. In each case, also, samples of the A and B horizons of the virgin soil above the irrigation canal were taken for comparison. Table 1 gives the description and location of the samples taken from these ranches.

NOTES ON SOIL SAMPLES

Soil 1 and 2—F. Kirk Johnson, Saratoga, Wyoming.—Samples taken on alfalfa field; had grain (oats) 7 years ago and alfalfa continuously 14 years before. Never had manure. Yields about 1½ tons per acre. Saratoga loam; gravelly bench land, sloping. Took virgin sample in sage east of house.

Soil 3 and 4—Winthrop Condict, Saratoga, Wyoming.—Sample of poor alfalfa 3 years old; cultivated grain 3 years; alfalfa inoculated; no manure. Seeded with oats for nurse. Poor grain, N, and P. Sample from black alkali spot east of house in draw; bare or weedy.

Soil 5 and 6—George Meason, Saratoga, Wyoming.—Alfalfa field seeded 1898 has had alfalfa continuously; two crops yearly. Yields 2½ tons per year; about 1½ tons this year. Has been dying out gradually. Winter killed 8 years ago.

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TABLE 1.—*Source of soil samples.*

Owner	Alfalfa series	Depth, inches	Soil type
Johnson	1A, cultivated soil	0–8	Loam
Johnson	1B, cultivated soil	8–24	Loam
Johnson	2A, virgin soil	0–8	Loam
Johnson	2B, virgin soil	8–24	Loam
W. Condict	3A, cultivated soil	0–8	Residual granitic
W. Condict	3B, cultivated soil	8–24	Residual granitic
W. Condict	4A, grass (pasture)	0–8	Black alkali
Meason	5A, cultivated soil	0–8	Residual fine sandy loam
Meason	5B, cultivated soil	8–24	Residual fine sandy loam
Meason	6A, virgin soil	0–8	Residual fine sandy loam
Meason	6B, virgin soil	8–24	Residual fine sandy loam
Sears	7A, cultivated soil	0–8	Loam
Sears	7B, cultivated soil	8–24	Loam
Sears	8A, virgin soil	0–8	Fine sandy loam
Sears	8B, virgin soil	8–24	Fine sandy loam
Jas. Sowder	9A, cultivated soil	0–8	Fine sandy loam
Jas. Sowder	9B, cultivated soil	8–24	Loam
Jas. Sowder	10A, virgin soil	0–8	Fine sandy loam
Jas. Sowder	10B, virgin soil	8–24	Fine sandy loam
Davis	11A, cultivated soil	0–8	Loam
Davis	11B, cultivated soil	8–24	Loam
Davis	12A, virgin soil	0–8	Fine sandy loam
Davis	12B, virgin soil	8–24	Fine sandy loam
Foreman	13A, cultivated soil	0–8	Loam
Foreman	13B, cultivated soil	8–24	Loam
Foreman	14A, virgin soil	0–8	Loam
Foreman	14B, virgin soil	8–24	Loam

Soil 7 and 8—Sears.—Alfalfa sample on grain field; 25 years alfalfa and 5 years grain. Mr. Sears says it cost $25 per acre to prepare sage land and raise a crop of grain on it in 1920; returns $83, net $58. On alfalfa at 4 tons per acre the net return is about $25 per acre now. Not much trouble with dandelions.

Soil 9 and 10—Jas. Sowder.—Took sample south of road to house in alfalfa on gentle slope (fine sandy loam). Has had alfalfa 27 years with 3 years of grain; plowed up twice in that time; dandelion trouble. Took virgin sample above ditch in same slope in sage-bench soil. Has good stand alfalfa.

Soil 11 and 12—Davis.—Collected sample below big ditch and north of road or lane below Davis station. Was seeded to alfalfa in 1890 and has been in that crop most of the time. Killed out by over irrigation once or twice and re-seeded. Virgin sample above track at Davis station.

Soil 13 and 14—Dan Foreman.—Took sample on bench soil above house in alfalfa which was seeded on new breaking in 1911; has good yield, thick stand, no weed troubles. Mr. Foreman says that bench farms are adapted to alfalfa. Pastures hogs on alfalfa (rotate) and

finishes them on oats, barley, and wheat. Uses common alfalfa seed; does not inoculate; can seed with oats first breaking after sage is off. Finds that disking alfalfa thickens the stand for 2 to 3 years; should be reseeded every 8 or 10 years (or disked). No trouble with dandelions yet.

RESULTS

NITROGEN

The samples were analyzed for total nitrogen by the modified Kjeldahl method with the results given in Table 2.

TABLE 2.—*Total nitrogen from virgin and from alfalfa soils.*

Soil	Nitrogen, %	Soil	Nitrogen, %
1A, alfalfa	0.110	8A, virgin	0.054
1B, alfalfa	0.092	8B, virgin	0.036
2A, virgin	0.090	9A, alfalfa	0.092
2B, virgin	0.073	9B, alfalfa	0.050
3A, alfalfa	0.115	10A, virgin	0.053
3B, alfalfa	0.082	10B, virgin	0.040
5A, alfalfa	0.051	11A, alfalfa	0.097
5B, alfalfa	0.046	11B, alfalfa	0.083
6A, virgin	0.046	12A, virgin	0.072
6B, virgin	0.043	12B, virgin	0.054
7A, alfalfa	0.088	13A, alfalfa	0.061
7B, alfalfa	0.117	13B, alfalfa	0.061
		14A, virgin	0.052
		14B, virgin	0.044

The average alfalfa field had 0.088% N in the surface soil and 0.076% in the subsoil, while the virgin field had 0.061% N in the surface soil and 0.048% in the subsoil.

It is immediately evident that the combined effect of irrigation and alfalfa growing resulted in a large increase of the store of nitrogen, both in the surface and subsoil horizons of these soils. The average increase in the surface soil was 0.027%, or 270 pounds nitrogen per million pounds of soil, while the gain in the subsoil was 0.028%, or 280 pounds of nitrogen per million pounds of soil.

The average term of alfalfa growing on these fields was 24 years so that about 11 or 12 pounds of nitrogen per million pounds of soil have been acquired for each year of alfalfa growing. The increase of total organic matter would be in the neighborhood of 20 times these

amounts, representing a total gain of around 15 tons of organic matter per acre to a depth of 18 inches (6,000,000 pounds) in these soils.

AVAILABLE PLANT FOOD

The colorimetric determination of available phosphate generally gives results which compare favorably with field tests on Wyoming soils except where large amounts of basic material, such as alkali or lime, occurs in the subsoil. In Table 3 is given the available phosphorus as determined by the Truog modification of the Denige method.

TABLE 3.—*Available phosphorus in Saratoga soils in parts per million.*

Soil	Phosphorus		Cropping treatment	Soil	Phosphorus		Cropping treatment
	Mineral	Organic			Mineral	Organic	
1A	30	26	Alfalfa	8A	12	18	Virgin
1B	25	16	Alfalfa	8B	17	10	Virgin
2A	32	38	Virgin	9A	45	20	Alfalfa
2B	28	36	Virgin	9B	75	15	Alfalfa
3A	50	33	Alfalfa	10A	41	53	Virgin
3B	44	40	Alfalfa	10B	25	75	Virgin
5A	28	10	Alfalfa	11A	33	16	Alfalfa
5B	36	4	Alfalfa	11B	30	11	Alfalfa
6A	34	53	Virgin	12A	14	42	Virgin
6B	37	43	Virgin	12B	19	26	Virgin
7A	27	20	Alfalfa	13A	30	14	Alfalfa
7B	42	13	Alfalfa	13B	36	18	Alfalfa
				14A	30	65	Virgin
				14B	27	64	Virgin

If 30 to 35 p.p.m. be taken as the point at which our soils begin to respond to phosphate applications, it is evident that these soils could be profitably treated with superphosphate, especially for sugar beet production.

There seems to have been no large reduction in the available phosphate due to alfalfa growing. The reduction, if any, seems to be in the organic forms of phosphorus which is large in the virgin soils and lower in the alfalfa soils. On the whole, it is necessary to conclude that the relatively small stores of available plant food originally characteristic of most of the virgin soils have not been adversely affected by irrigation and by alfalfa production.

SOIL REACTION

The effect of irrigated alfalfa upon the soils has in some cases resulted in a considerable decrease of basic reaction. Some of the irrigated soils have become more basic than the virgin soil. Table 4 shows the reaction of the virgin and alfalfa soils by the colorimetric method.

TABLE 4.—*Reaction of virgin and irrigated alfalfa soils.*

Soil	Description	pH	Soil	Description	pH
1A 1B	Cultivated brown loam, sloping bench land; low yield	8.9 8.5	9A 9B	Cultivated brown fine sandy loam, bench land	7.5 7.6
2A 2B	Virgin sage brush as above	8.9 8.9	10A 10B	Virgin soil as above	7.5 7.7
3A	Poor alfalfa, brown loam on granite	7.9	11A 11B	Brown loam, bench soil	7.7 8.1
5A 5B	Cultivated gray brown fine sandy loam on sandstone	7.7 7.7	12A 12B	Brown fine sandy loam, bench soil, virgin as above	8.7 8.1
6A 6B	Virgin soil as above	7.9 7.9	13A 13B	Brown loam, bench soil, good alfalfa	8.1 8.1
7A 7B	Brown loam cultivated, bench land, good yield	8.1 8.3	14A 14B	Brown loam as above Virgin soil	7.6 7.4
8A 8B	Brown fine sandy loam Virgin soil	8.5 8.5			

The average reaction of soil and subsoil is pH 8.0. Basic material may be brought to the soil by the water used as well as being removed by percolation of excess water into the subsoil. The oldest fields, Nos. 7 and 11, which have been in alfalfa from 25 to 35 years, seem to show considerable reduction in basic reaction.

MIGRATION OF BASES AND SESQUI-OXIDES

Under the influence of such large amounts of organic matter as have accumulated in these irrigated alfalfa soils, it might be supposed that some transfer of mineral matter from surface to subsoil, or vice versa, might have occurred. The large amounts of water used over a prolonged period also might have had an appreciable effect in leaching away some of the more soluble matter. The leaching effects might be expected to be different in amount in the high-lime than in the low-lime soils. Table 5 shows the strong HCl digestion results of the virgin and alfalfa soils.

TABLE 5.—*Silica, bases, and sesqui-oxides in virgin and alfalfa soils.*

Soil No.	Cropping	Percentage of		Fe-Al oxides
		Silicon	Ca-Mg oxides	
	High-lime Surface Soils			
1	Alfalfa	0.05	3.45	3.08
2	Virgin	0.08	2.08	2.74
7	Alfalfa	0.05	0.87	2.33
8	Virgin	0.09	6.90	1.37
12	Virgin	0.08	6.96	4.20
13	Alfalfa	0.10	2.27	3.96
	High-lime Subsoils			
1	Alfalfa	0.91	20.49	3.45
2	Virgin	0.23	14.32	2.97
7	Alfalfa	0.26	1.93	3.53
8	Virgin	0.24	12.02	3.68
11	Alfalfa	0.56	11.46	3.09
12	Virgin	0.41	11.84	4.46
	Low-lime Surface Soils			
3	Alfalfa	0.12	0.62	3.89
5	Alfalfa	0.06	0.56	1.97
6	Virgin	0.04	0.33	2.05
9	Alfalfa	0.07	0.23	2.34
10	Virgin	0.10	0.34	3.01
11	Alfalfa	0.06	0.41	2.43
14	Virgin	0.04	0.38	2.99
	Low-lime Subsoil			
5	Alfalfa	0.24	0.78	2.81
6	Virgin	0.21	0.64	3.19
9	Alfalfa	0.29	0.74	3.41
10	Virgin	0.32	0.60	3.58
13	Alfalfa	0.40	1.33	3.38
14	Virgin	0.26	0.81	3.74

Table 6 contains the chemical data summarized according to average high-lime and average low-lime soils.

DISCUSSION

There seems to be a slight increase in the amounts or in the solubility of the silica in the irrigated alfalfa soils. The removal of bases is very marked in the high-lime soils, 58% appearing to be removed from the surface soil and 10% from the subsoil. In the low-lime soils, alfalfa seems to have increased the Ca-Mg content of the A horizon by 28% and of the B horizon by 39%, possibly by extracting it from the parent soil beneath. Iron and alumina have also increased in the surface of the high-lime soils apparently at the expense of the B and C horizons beneath. In the low-lime soils, the sesqui-oxides have changed very little under cropping.

TABLE 6.—*Average composition of old alfalfa and virgin soils.*

Soil	Percentage of				Available phosphorus in p.p.m.	pH
	SiO_2	Ca-Mg oxides	Fe-Al oxides	Nitrogen		
High-lime surface soil:						
Virgin	0.082	5.316	2.772	0.072	19	8.7
Alfalfa	0.068	2.198	3.122	0.086	23	8.3
High-lime subsoil:						
Virgin	0.292	12.658	1.852	0.054	21	8.5
Alfalfa	0.392	11.308	1.354	0.097	32	8.2
Low-lime surface soil:						
Virgin	0.064	0.354	2.686	0.050	35	7.7
Alfalfa	0.076	0.454	2.658	0.089	39	7.8
Low-lime subsoil:						
Virgin	0.264	0.682	3.504	0.042	29	7.7
Alfalfa	0.310	0.950	3.198	0.052	49	7.8

The smallest accumulation of organic matter and nitrogen seems to have occurred in the B horizon of the low-lime soils. The largest gains are shown in the B horizon of the high-lime soils and in the A horizon of the low-lime soils. These gains represent increases of 15 to 16 tons of organic matter per acre 18 inches deep (6,000,000 pounds soil) during an average of 24 years of irrigation and alfalfa growing.

The low-lime soils show more adequate amounts of available phosphorus and somewhat better stands of alfalfa in the field. Wyoming irrigated soils respond to phosphate application when this method shows 35 to 40 p.p.m. of available phosphorus so that most of these soils need phosphate application.

SUMMARY

Alfalfa growing on irrigated land builds up the organic matter and nitrogen content of arid soils and seems to bring up iron from the subsoil, counteracting the effects of too high lime content in the surface soils. Alfalfa should be rotated with cultivated crops or applications of superphosphate resorted to in order to keep up the yields on the older fields which are low in available phosphates.

Irrigation removes large amounts of basic material from the high-lime soils and increases the amount or solubility of silica, especially in the subsoils. The average reaction of the high-lime soils has been appreciably lowered, but that of the low-lime soils has not been affected.

THE EFFECT OF PREVENTING FRUITING AND OF REDUCING THE LEAF AREA ON THE ACCUMULATION OF SUGARS IN THE CORN STEM[1]

J. D. Sayre, V. H. Morris, and F. D. Richey[2]

During a study of the distribution of sugars in the maturing corn stem (1),[3] it was found that there was a considerable accumulation of sugars, particularly sucrose, during the period from silking to maturity. In order to obtain more information on this phase of corn physiology, a study was undertaken of the effect of such operations as reducing the leaf area and bagging the ear shoot, thus preventing fruiting, on the accumulation of sugars in the stem. The latter factor is of special interest in connection with the widespread natural barrenness brought about by the drouth of 1930.

Willaman, Burr, and Davison (2) found that after removing the ears of both sweet and field corn at canning time, the total sugar content of the stem juice increased markedly, the increase amounting to as much as 50%. Dungan (3) found a reduction in quality and yield of grain when the leaf area was reduced, no analytical data being reported.

MATERIAL AND METHODS

The variety of corn used in this study was Burr-Leaming, a double cross. As soon as the plants had tasseled (about August 24) groups of 60 plants were treated as follows: (A) The ear shoot was bagged to prevent pollination; (B) four leaves, from the one above the ear node to the second below, were removed; (C) all leaves except those designated in (B) were removed.

At intervals of 10 days after the treatment, 10 plants were taken from each lot, a similar sample being taken from normal corn to serve as a check. The leaves, sheaths, and tassels were discarded. The stems of each sample were passed through a food grinder, the sap expressed, the sugar in the expressed sap determined, and the percentage of sugar in the original green tissue calculated as described in a previous paper (4).

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., based on cooperative investigations between the Ohio Agricultural Experiment Station, Wooster, Ohio, and the Office of Cereal Crops and Diseases. Received for publication March 11, 1931.

[2]Assistant in Agronomy and Associate Agronomist, Ohio Experiment Station, and Principal Agronomist in Charge of Corn Investigations, U. S. Dept. of Agriculture, respectively.

[3]Reference by number is to "Literature Cited," p. 753.

Samples of stalks barren because of the drouth were compared with plants of similar size but bearing normal ears, both taken from the same field of Burr-Leaming corn on October 3, 1930.

RESULTS

The effects of reducing the leaf area and of preventing pollination on the total sugar content of the corn stem are shown in Fig. 1. In the stems of the plants where pollination was prevented, the total sugar gradually increased until September 23, when it had reached a maximum content of about 10.5%. Stems of the normal plants had a maximum content of 9.0% on September 11, and this had decreased to 7.9% by September 23.

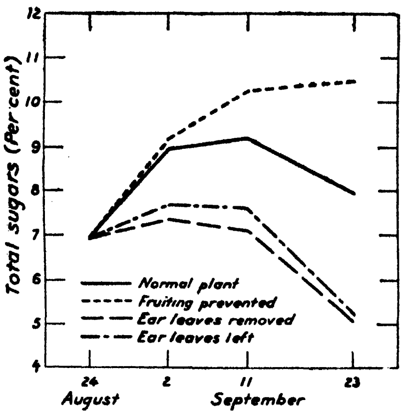

FIG. 1.—Percentage of total sugars in the stems of corn plants.

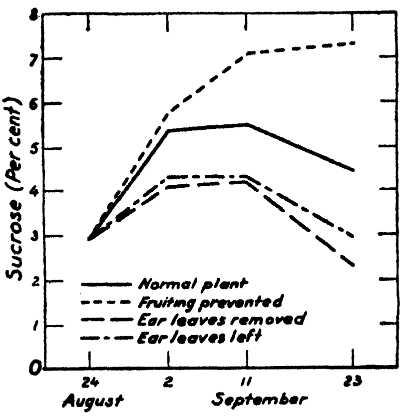

FIG. 2.—Percentage of sucrose in the stems of corn plants.

Reducing the leaf area lowered the total sugar content of the stems. Removing the four leaves about the ear decreased the total sugar content 2.8% on the average, as compared with normal plants. Removing the upper and lower leaves decreased the total sugars 2.5%.

That the effect of these treatments on the total sugar content of the corn stem is due to changes in the sucrose rather than to changes in reducing sugars is shown by a comparison of Figs. 2 and 3.

The reducing sugar content of the stems was virtually unaffected, whereas the changes in sucrose due to the treatments were large enough to account for the changes in total sugars. This result is similar to those obtained by Willaman, Burr, and Davison (2) in their investigations on corn stem juice.

Although yields were not determined quantitatively in these experiments, observation indicated that the reductions in leaf area were associated with reductions in quantity and quality of the grain similar to those reported by Dungan (3).

TABLE 1.—*Comparison of sugars in the stems of corn plants bearing normal ears and in barren corn plants.**

Sample	Total sugars, %	Free reducing sugars, %	Sucrose, %
Normal	8.70	2.17	6.54
Barren	11.78	1.90	9.87

*Results expressed as percentages on fresh weight basis.

That natural barrenness brought about by unfavorable weather conditions also results in an increase in total sugars was shown by the analyses of 1930 samples, given in Table 1. Here, also, the increase in total sugars was due to increase in sucrose. Where the stover is fed, this increase compensates in part for the loss of the grain.

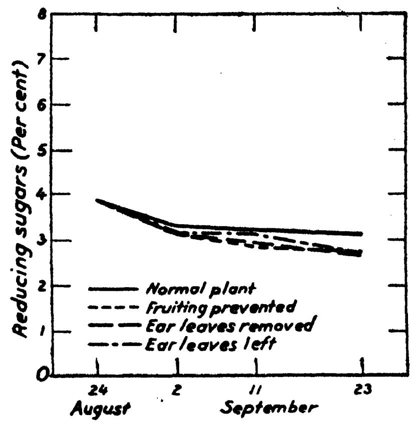

FIG. 3.—Percentage of reducing sugars in the stems of corn plants.

SUMMARY

1. Preventing pollination, and consequently fruiting, was associated with a gradual accumulation of total sugars.
2. Barrenness brought about by the drought resulted in a similar accumulation of total sugars.
3. Reduction in leaf area was associated with a reduction in the total sugar content of the stem.
4. The changes in total sugar content were due to changes in the sucrose content of the tissue and not to free reducing sugars.

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THE COMPARATIVE PROTEIN CONTENT OF ALFALFA AND RED CLOVER[1]

C. J. WILLARD[2]

It is commonly believed that alfalfa hay has a much higher protein content than red clover hay. The analyses usually given and, for that matter, the ordinary farm experiences with these two feeds, bear out this idea. Henry and Morrison[3], for example, give the following figures:

	Alfalfa	Red clover
	%	%
Crude protein, all analyses	14.9	12.8
Digestibility, all determinations	71	59
Digestible protein, all analyses	10.6	7.6

In studies on the stage of harvesting alfalfa for hay, it occurred to the writer that a considerable proportion or perhaps all of this difference might be caused by the difference in maturity at the usual time of harvesting the two crops. Alfalfa came into American agriculture from the West, and with it came a tradition of early and frequent cutting. Until recently little alfalfa was cut as late as the full-bloom stage, unless from inability to harvest it earlier. Red clover, on the other hand, is usually cut quite late in its life history. The common practice of mixing red clover with timothy, which matures decidedly later than red clover, has been an important factor in delaying the clover harvest, and the opinion of most farmers is that red clover does not suffer seriously by delayed harvesting. In farm practice, red clover has certainly been cut at a much more mature stage than alfalfa. In central Ohio, June 10 is probably an average date for making the first cutting of alfalfa, while June 25 will be nearer the average date for red clover. It is difficult to judge the maturity of either crop by the bloom, but the full-bloom stage for both at Columbus will come about June 15 in an ordinary season.

In our experiments at Columbus, a considerable number of comparisons have been made between red clover and alfalfa which were sown at the same time on the same soil type and which were harvested the same day. These comparisons are given in Table 1. The simi-

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication March 26, 1931.

[2]Associate in Agronomy, Ohio Agricultural Experiment Station, and Professor of Farm Crops, The Ohio State University.

[3]Henry, W. A., and Morrison, F. B. Feeds and Feeding. Ed. 18. 1923.

larity of these samples in protein content is evident at a glance. As an average of the 17 comparisons, the percentage of crude protein in alfalfa is only 0.1% greater than that in red clover.

It is noticeable in Table 1 that when harvests of the two crops were made on successively later dates, the percentage of protein decreased rapidly, and at substantially the same rate in each crop. Many other observations of the two crops are in agreement with this. Therefore, since we know that the usual dates of cutting have differed, the most reasonable explanation of the difference in the average analyses generally reported is that it is caused by the difference in the average date of cutting.

Most writers on alfalfa give 3% as the average difference in protein content between alfalfa and red clover, referring to the digestible portion of the protein. We know from numerous experiments that the digestibility of most forages decreases rapidly as they become more mature. It seems quite probable, therefore, that the lower average digestibility of protein in red clover, reported above, is also due in considerable measure to the fact that the samples of red clover had been cut at a later stage of maturity than the alfalfa samples.

TABLE 1.—*Comparisons of the protein content of red clover and alfalfa sown at the same time on adjacent or nearby plats and harvested on the same date.*

Date of harvest	Date of seeding and treatment	Percentage protein in hay	
		Red clover	Alfalfa
June 14, 1923	April, 1922	13.1	13.9
June 6, 1925	April, 1924	14.8	15.3
May 30, 1928	April, 1927, clipped Sept. 1, 1927	20.9	21.0
May 30, 1928	April, 1927, clipped Nov. 1, 1927	20.9	20.6
May 30, 1928	April, 1927, not clipped, 1927	20.3	19.8
June 1, 1929	April, 1928	17.1	17.2
June 7, 1929	April, 1928	14.3	16.8
June 14, 1929	April, 1928	15.2	15.2
May 17, 1930	April, 1929, clipped Aug. 15, 1929	18.4	18.4
May 30, 1930	April, 1929, clipped Sept. 1, 1929	15.8	16.4
May 30, 1930	April, 1929, clipped Nov. 1, 1929	17.9	17.3
May 30, 1930	April, 1929, not clipped, 1929	16.3	17.3
June 6, 1930	April, 1929, clipped Sept. 1, 1929	15.6	15.1
June 6, 1930	April, 1929, clipped Nov. 1, 1929	15.8	14.7
June 6, 1930	April, 1929, not clipped, 1929	14.9	14.9
June 14, 1930	April 1929, clipped Aug. 15, 1929	14.1	14.5
June 11, 1930	July, 1929	16.0	15.5
Average, 17 comparisons		16.6	16.7

CONCLUSION

The commonly accepted and reported difference in protein content between red clover and alfalfa is due largely, if not entirely, to the fact that alfalfa is usually cut earlier in the season and at an earlier stage of maturity than red clover.

AGRONOMIC AFFAIRS

THE ANNUAL MEETING

Plans for the twenty-fourth annual meeting of the Society, to be held in the Stevens Hotel in Chicago, November 19 and 20, are rapidly taking shape. The morning period on the first day will be devoted to a business session, including the reports of officers and committees. The business of the Society has assumed such proportions that the time available at the banquet is no longer sufficient for an adequate discussion of the many important matters that come before the Society.

Four symposia topics have been arranged as follows: Cold and Drought Resistance in Plants, R. I. Throckmorton in charge; Soil Organic Matter and Soil Classification, S. A. Waksman in charge; The Relation of Calcium and Magnesium Compounds to Soil Conditions and Plant Growth, A. B. Beaumont in charge; and Soybeans, W. J. Morse in charge.

On Friday afternoon there will be an open session for the presentation of papers by members of the Society. For a place on this part of the program, titles of papers must be in the hands of the Secretary not later than October 1, together with a statement of the time required to present the paper and an abstract of not more than 200 words.

Abstracts of all papers, including the symposia papers, will be printed in advance of the meeting and will be available at the registration desk.

The Secretary has made arrangements with the Land Grant College Association and the railroads for the Society to be included in the railroad certificate plan used by the Land Grant College Association last year. All of those who attend the meeting are urged, therefore, to buy one-way tickets to Chicago for themselves and members of their families who may accompany them and to obtain from their ticket agent the necessary certificate. These certificates will be validated at Chicago and will entitle the holder to a return ticket at half fare.

Exhibits from laboratory supply houses, fertilizer manufacturers, and others are also expected to form a feature of the Chicago meeting.

NEWS ITEMS

Dr. R. A. Oakley, Senior Agronomist, in Charge of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and a member of the American Society of Agronomy since 1910 and a Fellow of the Society since 1927, died in Monrovia, Calif., on August 6, following a long illness.

According to *Science*, Dr. J. H. Parker of the Department of Agronomy, Kansas State Agricultural College, has been named acting Professor of Plant Breeding for 1931–32 at Cornell University in place of Dr. H. H. Love who is on leave of absence in China.

Carrol P. Wilsie, who secured his Ph. D. degree at Michigan State College and who has held a fellowship of the National Milling Company for several years, is now agronomist at the Hawaii Agricultural Experiment Station, Honolulu, T. H.

H. E. HAMMAR, who received his doctorate in soil microbiology and chemistry at Rutgers University last June, has been appointed research associate in the Geological Survey and chemist for the American Petroleum Institute, with headquarters in the Bureau of Standards at Washington, D. C.

DURING the past year the Agronomy and Plant Genetics Division, University of Minnesota, has conferred 12 advanced degrees, 8 doctorates and 4 masters. The countries represented in graduate study included Canada, New Zealand, Germany, Haiti, Peru, and Alaska. L. R. Powers and I. J. Johnson, who received their doctorates, were each given the rank of assistant professor.

S. M. RALEIGH resigned as Assistant in Agronomy, University of Minnesota, to accept a position as Agent in the Office of Sugar Plants, U. S. Dept. of Agriculture. His place was taken by D. M. Hall, formerly agricultural instructor of the Newton, Iowa, high school.

D. C. SMITH, formerly of the Oregon State Agricultural College, has been given a Research Fellowship in Plant Breeding under a fund awarded by the Minnesota Valley Canning Company for sweet corn improvement.

Dr. H. E. BREWBAKER, Office of Sugar Plants, U. S. Dept. of Agriculture, Fort Collins, Colo., spent six weeks with the Agronomy and Plant Genetics Division, University of Minnesota. During this time Dr. Brewbaker was enrolled in the statistical course taught by Dr. R. A. Fisher of the Rothamsted Experiment Station.

C. E. CARTER and ROBERT L. MATLOCK have been awarded the degree of Doctor of Philosophy in Agronomy at the University of Illinois. Dr. Carter has returned to his former position in agronomy extension at the University of Missouri and Dr. Matlock has been appointed Acting Head of Agronomy at the University of Arizona.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 OCTOBER, 1931 NO. 10

PHOSPHATE PENETRATION IN FIELD SOILS[1]

R. E. STEPHENSON and H. D. CHAPMAN[2]

The results of numerous lysimeter and soil investigations have shown that phosphorus tends to accumulate in the soil horizons in which it is incorporated, and that in most soils movement away from this zone is very slow. There is little evidence in any of this work as to the rate of movement of the phosphorus in different phosphate fertilizers, and almost no data relative to the effect of manner and amount of application on the extent of movement. Moreover, very little definite information exists as to the natural and induced soil characteristics which affect the direction and rapidity of phosphorus translocation in soils.

For the purpose of finding out the extent to which phosphate had penetrated into certain field soils which have received phosphorus-carrying fertilizers for a number of years, a special field study has been made. The results of this investigation, together with the preliminary findings of a study on the comparative rates of penetration in soils of the phosphorus in ammonium phosphate and triple superphosphate, are presented in this paper.

METHODS OF STUDY

For the field study, the phosphorus content of soil samples taken from citrus fertilizer plats, citrus groves, date gardens, and fields which had been fertilized for varying periods of time were compared with the phosphorus content of samples taken from adjacent

[1]Contribution from University of California Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, Calif. Paper No. 246. Received for publication March 13, 1931.

[2]Associate Professor of Soils, Oregon State Agricultural College, Corvallis, Ore., and Assistant Chemist, California Citrus Experiment Station, Riverside, Calif., respectively. The senior author wishes to express his gratitude to Dr. W. P. Kelley and to Director L. D. Batchelor for privileges enjoyed at the Citrus Experiment Station.

plats or fields which had had no phosphate fertilizer. Composite samples of the horizons 0 to 6 inches, 6 to 12 inches, 12 to 24 inches, and 24 to 36 inches were secured in nearly all cases. The soils were brought to the laboratory, air dried, 20-meshed, and determinations made of water- and acid-soluble PO_4 and of the pH.

In all cases an attempt was made to secure as complete a fertilizational history as possible. With those soils which came from experimental plats, this information is exact, and an estimation of the total phosphate applied to the fertilized soil has been made.[3]

Although complete data on the manner of fertilizer application could not always be obtained, it is safe to assume that cultural operations, such as furrowing or basining for irrigation, turning under of cover crops, cultivation, and occasional plowing, have caused fertilizer to be mechanically incorporated to depths of from 6 to 9 inches. Therefore, only such increases in phosphate as are found below the first foot horizon can be considered as having been moved there by causes other than mechanical.

The total water received by orchards devoted to citrus culture, including rainfall and irrigation, will range on the average from 35 to 60 acre-inches annually. In the date gardens, from which samples were removed, irrigation water is almost exclusively the source of soil moisture and amounts of water varying on the average from 80 to 120 acre-inches annually are commonly supplied.

In an attempt to convey some impression as to the relative physical state of the soils sampled, they have been roughly classified according to their degree of compaction. This information is recorded in Table 1. All of the soils studied are low in organic matter and neutral to slightly alkaline in reaction.

For the purpose of gaining some exact information on the comparative rate of downward movement of the phosphorus in various phosphate-containing fertilizers, a special field experiment has been set up at the Citrus Experiment Station. A level, apparently uniform soil was chosen and galvanized iron cylinders, open at both ends, were driven into the ground to a depth of 6 inches. The cylinders were so arranged as to be 3 feet apart each way. Levees were thrown up around the entire area and the surface within this basin made level.

[3]In citrus orchards the tree is ordinarily the unit of fertilization and to convert pounds per tree to pounds per acre, a uniform average of 90 trees per acre has been assumed. Inasmuch as some orchards will average more and some less than this, the calculated amounts per acre may be somewhat in error. In certain orchards, fertilizer is not always applied to the entire soil area, and in such cases the actual amounts calculated in terms of rate per acre are somewhat less than the real rate. Soil samples were taken only from areas actually fertilized.

The various fertilizers at the rate of 200 pounds phosphoric acid per acre were incorporated into the surface 4 inches of the cylinders. The treatments were in duplicate and nontreated cylinders were also included for checks. Enough separate cylinders for each treatment were provided in order that a new set would be available for each sampling. It was planned to imitate citrus irrigation practice as nearly as possible by applying water at the rate of approximately 4 acre-inches every month except during such periods in which sufficient rain fell to supply approximately this amount. At intervals during the continuance of this experiment it was aimed to take samples of comparable horizons in the differently treated cylinders and make determinations of water-soluble phosphate. In the absence of the interfering action of plants and with an apparently uniform soil it appeared possible by this method to secure fairly accurate information as to the comparative rate of movement of the phosphorus in these different phosphate fertilizers under conditions which approximate those of the field. The results obtained to date with ammonium phosphate and double superphosphate are recorded in Table 2 and will be discussed later in this paper.

CHEMICAL METHODS USED

Water-soluble phosphate was determined on an extract of a 1 to 5 soil-water suspension. The suspension was shaken 1 hour, allowed to settle 15 minutes, and then filtered by suction through a Buechner funnel, utilizing an apparatus patterned after that described by Truog (3).[4] In this method of filtering it is essential that the first clear extract obtained be used for the phosphate determination for as soon as the soil forms a mat on the filter paper more or less reabsorption of phosphate from the suspension will take place. Carbon dioxide-free water was used in all of the determinations.

Acid-soluble phosphate was determined by a method recently described by Truog (4). In this method the soil is extracted by 0.002 N sulfuric acid buffered to pH 3.0 with ammonium sulfate. A modification of the Deniges colorimetric method was used for the determination of phosphate in both water and acid extracts. Soil reaction was estimated by means of the quinhydrone electrode.

DISCUSSION OF RESULTS

The field data secured are presented in Table 1. Although the soil type in all comparisons has been the same, it is realized that neither water nor acid extracts of soil samples from comparable

[4]Reference by number is to "Literature Cited," p. 770.

TABLE 1.—*Phosphate penetration in field soils.*

Location	Soil type	Comparison No.	Crop	Fertilizer treatment	Number of years fertilized	Approximate total of PO_4 applied, lbs. per acre	Water-soluble PO_4 in p.p.m. of soil				Acid-soluble PO_4 in p.p.m. of soil			
							0–6 in.	6–12 in.	12–24 in.	24–36 in.	0–6 in.	6–12 in.	12–24 in.	24–36 in.
Citrus Exp. Sta., Rubidoux plats	Sierra loam; moderately compact	1	Oranges	None	—	—	5.7	3.6	2.9	5.7	370.0	342.0	430.0	496.0
			Oranges	Superphosphate	22	6,340	20.4	72.4	34.3	9.9	2,320.0	1,380.0	543.0	334.0
			Oranges	Complete 5–10–5	22	5,860	30.5	33.0	26.7	8.6	2,178.0	1,320.0	548.0	378.0
			Oranges	Manure	22	1,870	38.0	24.4	14.6	13.7	966.0	706.0	456.0	462.0
			Oranges	Steamed bone	22	6,340	2.9	1.6	1.6	2.9	1,600.0	1,080.0	360.0	382.0
			Oranges	Steamed bone	22	6,340	1.5	0.6	0.5	2.3	1,620.0	874.0	318.0	354.0
			Oranges	None	—	—	4.6	3.6	3.6	2.3	288.0	276.0	300.0	386.0
Citrus Exp. Sta. plats, Field I	Ramona loam; moderately compact	2	Oranges	None	—	—	9.5	5.7	4.6	2.8	166.0	112.0	120.0	234.0
			Oranges	None	—	—	10.2	5.3	2.8	2.3	130.0	172.0	162.0	336.0
			Oranges	Urea	3	—	9.7	7.6	6.7	3.4	156.0	148.0	238.0	398.0
			Oranges	Urea	3	—	11.7	5.3	2.2	1.5	122.0	118.0	116.0	356.0
			Oranges	Urea, triple superphosphate	3	361	21.4	10.2	4.9	1.9	242.0	246.0	238.0	370.0
			Oranges	Urea, triple superphosphate	3	361	19.3	13.2	3.7	0.9	224.0	214.0	147.0	282.0
			Oranges	Urea, K_2SO_4, triple superphosphate	3	361	22.8	11.7	4.5	3.4	280.0	310.0	286.0	396.0
			Oranges	Urea, K_2SO_4, triple superphosphate	3	361	20.3	9.8	2.9	2.1	226.0	156.0	136.0	334.0
Chaffey Junior College	Hanford gravelly sandy loam; loosely compacted	3	Oranges	$(NH_4)_2SO_4$	15	—	13.0	3.4	4.6	2.7	266.0	152.0	194.0	156.0
			Oranges	6–8–4	15	7,290	36.2	44.2	27.9	32.0	880.0	662.0	342.0	316.0
Fontana Farms	Hanford gravelly sandy loam; loosely compacted	4	Oranges	None	—	—	9.7	8.9	8.1	—	172.0	178.0	186.0	—
			Oranges	Garbage manure	8	720	27.4	16.8	15.2	—	600.0	178.0	154.0	—
			Oranges	Garbage manure, superphosphate	18	3,220	133.4	38.1	29.0	29.0*	1,280.0	434.0	308.0	308.0*
Orange Co. Farm	Hanford loam; moderately compact	5	Oranges	Nitrogen	7	—	1.5	0.5	Trace	Trace	262.0	232.0	96.0	44.0
			Oranges	Superphosphate	7	1,350	6.9	1.9	Trace	Trace	620.0	392.0	148.0	70.0

Orange Co. Plat	Hanford loam; moderately compact	6	Oranges	Nitrogen	7	——	6.1	2.1	0.9	0.5	1,020.0	800.0	635.0	542.0
			Oranges	Superphosphate	7	1,350	16.2	4.2	1.3	0.9	1,240.0	764.0	606.0	544.0
Moreno Valley	Ramona sandy loam; moderately compact	7	Grain	None	—	——	9.5	3.9	3.4	4.2	378.0	346.0	320.0	294.0
			Oranges	Manure, complete commercial fertilizer	35–38	?	36.9	19.1	14.3	20.8	972.0	416.0	218.0	234.0
Moreno Valley	Ramona sandy loam; moderately compact	8	Grain	None	—	——	9.1	7.6	4.6	3.4	178.0	172.0	182.0	192.0
			Oranges	Manure, complete commercial fertilizer	27–30	?	32.6	15.2	9.5	9.1	880.0	348.0	244.0	240.0
Moreno Valley	Ramona sandy loam; moderately compact	9	Grain	None	—	——	4.8	4.4	3.2	2.8	118.0	96.0	102.0	126.0
			Oranges	Manure, alfalfa hay, complete commercial fertilizer	3–4	700†	82.6	40.7	19.7	4.6	668.0	236.0	198.0	170.0
Coachella Valley soils	Indio very fine sandy loam; moderately compact	10‡	Dates	Urea	3	——	3.8	0.3	0.3	Trace	346.0	258.0	122.0	232.0
			Dates	Urea, treble superphosphate	3	800	61.0	4.7	0.3	Trace	492.0	344.0	182.0	262.0
Coachella Valley soils	Indio fine sandy loam; moderately compact	11‡	Dates	Urea	3	——§	428.0	66.7	27.4	5.3	1,820.0	724.0	564.0	382.0
			Dates	Urea, treble superphosphate	3	400§	333.4	167.6	50.8	47.6	1,990.0	1,300.0	1,110.0	542.0
Coachella Valley soils	Coachella fine sand; loosely compacted	12‡	Dates	Urea and K_2SO_4	3	——	11.2	5.3	2.5	0.4	272.0	336.0	244.0	180.0
			Dates	Urea and K_2SO_4; treble superphosphate	3	800	51.4	14.2	7.6	1.1	808.0	342.0	258.0	156.0
Coachella Valley soils	Coachella fine sand; loosely compacted	13	Alfalfa	None	—	——	0.76	0.4	Trace	Trace	192.0	334.0	358.0	401.0
			Grapefruit	Manure, alfalfa hay, rock phosphate, sulfate	14	?	8.9	3.8	0.76	Trace	370.0	388.0	332.0	262.0
Imperial Valley soils	Holtville silty clay; very compact	14	Lettuce	$NaNO_3$	1	——	Trace	0.2	Trace	Trace	46.0	42.0	58.0	46.0
			Lettuce	$NaNO_3$, superphosphate	1	120	0.6	0.3	Trace	Trace	58.0	39.0	39.0	44.0
Imperial Valley soils	Holtville silty clay loam; very compact	15	Lettuce	$NaNO_3$	1	——	Trace	Trace	Trace	Trace	40.0	48.0	40.0	36.0
			Lettuce	$NaNO_3$, superphosphate	1	120	2.7	1.2	Trace	Trace	84.0	64.0	44.0	46.0

*From horizon 24–28 inches.

†Bulk of the fertilizer applied from Aug. 1926, up to time of sampling January 1930.

‡The differential treatments recorded here are superimposed on a uniform manure treatment given to the entire date garden, and as specified these differential treatments have been applied only 3 years.

§The treatments recorded here, and the uniform manurial treatments, have been given to small basins surrounding the palms, hence the actual rates of application are much greater than indicated. This accounts for abnormally high amounts of water-soluble PO_4 found.

TABLE 1.—*Concluded.*

Location	Soil type	Comparison No.	Crop	Fertilizer treatment	Number of years fertilized	Approximate total of PO_4 applied, lbs. per acre	Water-soluble PO_4 in p.p.m. of soil				Acid-soluble PO_4 in p.p..m of soil			
							0–6 in.	6–12 in.	12–24 in.	24–36 in.	0–6 in.	6–12 in.	12–24 in.	24–36 in.
Imperial Valley soils	Holtville silty clay loam; very compact	16	Lettuce	$NaNO_3$	1	—	0.5	Trace	Trace	Trace	50.0	50.0	44.0	34.0
			Lettuce	$NaNO_3$, Ammo-phos, superphosphate	1	284	3.2	0.5	Trace	Trace	80.0	62.0	50.0	58.0
Imperial Valley soils	Imperial silty clay; very compact	17	Alfalfa	None	—	—	Trace	Trace	Trace	Trace	64.0	52.0	38.0	44.0
			Lettuce	Superphosphate	2	386	2.2	2.2	Trace	Trace	102.0	102.0	48.0	44.0
Imperial Valley soil	Meloland fine sandy loam; compact	18	Grapefruit	None	—	—	Trace	Trace	Trace	Trace	84.0	84.0	74.0	43.0
			Grapefruit	Manure	5	200	8.4	8.4	5.5	0.8	180.0	180.0	168.0	132.0
Tulare Co.	Hanford sandy loam; moderately compact	19	Oranges	Nitrogen	—	—	57.4	41.9	15.2	8.4	756.0	660.0	570.0	464.0
			Oranges	Nitrogen, treble superphosphate	1	877	110.5	119.4	15.2	9.5	1,130.0	924.0	456.0	380.0
Kern Co.	San Joaquin sandy loam; moderately compact	20	Oranges	Nitrogen	—	—	27.4	12.9	8.9	5.6	266.0	136.0	106.0	222.0
			Oranges	Nitrogen, treble superphosphate	1	877	72.4	78.0	47.6	14.5	496.0	—	180.0	170.0
Tulare Co.	Porterville clay loam adobe; very compact	21	Oranges	Nitrogen	—	—	10.2	Trace	Trace	Trace	336.0	170.0	128.0	66.0
			Oranges	Treble superphosphate	1	877	11.2	Trace	Trace	Trace	538.0	150.0	118.0	98.0
Orange Co.	Yolo clay adobe; very compact	22	Beans	None	—	—	6.1	3.5	1.1	1.0	560.0	606.0	584.0	638.0
			Oranges	Manure, bean straw	18	?	21.2	13.2	3.0	1.3	654.0	604.0	702.0	612.0

horizons of fertilized and unfertilized soils furnish certain proof of the movement or the lack of movement of phosphate. Non-uniformity in soils, the interfering influence of absorption by plant roots, and the variable fixing power of soils for phosphate may singly or in combination tend to obscure the real facts. However, in all of the soils studied the application of even small quantities of soluble phosphate fertilizers have given increases in the phosphate content of the water and acid extracts over those of unfertilized soils. Hence, if either the water or acid extract of a given sub-surface horizon of a fertilized soil shows a definite increase in phosphate over that in an unfertilized soil, it would seem to be fairly satisfactory evidence of phosphate movement. On the other hand, similarity in phosphate content of two such samples is not necessarily an indication of non-movement.

It will be noted that water extracts appear better adapted to show phosphate movement than acid extracts. Apparently the larger quantities of phosphate extracted by the acid render it impossible to detect with certainty those cases where movement has been slight. However, the acid extracts yield fairly reliable evidence as to accumulation of phosphate in any given horizon.

EFFECT OF SOIL TEXTURE AND STRUCTURE

Inspection of the results reveals that the data in general are in harmony with the expected influence of soil texture and structure on phosphate movement. In all of the comparisons on open, loosely compacted soils (comparisons 3, 4, 12, and 13) there is definite evidence of phosphate movement below the first foot. In comparisons 3 and 4, where considerable quantities of soluble phosphate have been supplied for a period of from 15 to 18 years, both the water and acid extracts reveal a marked penetration of phosphate into the second and third foot horizons.

With the moderately compacted soils the results are not as uniform. In general those soils which have been fertilized for many years (comparisons 1, 7, and 8) and some of those which have had a few heavy doses of soluble phosphate containing materials (comparisons 9, 11, and 20) show definite evidence of movement below the first foot. The results with those soils which have had only a few moderate applications (comparisons 2, 5, 6, and 10) are negative with respect to phosphate penetration.

In only one out of the six comparisons on very compact soils is there any evidence of phosphate movement below the first foot. This one soil (comparison 22) has received manure and bean straw for

18 years, and the water extracts indicate phosphate penetration into the second foot.

EFFECT OF RATE OF FERTILIZER APPLICATION

Although the data show strikingly that phosphate is largely fixed in the first 6 to 12 inches of soil and that movement into and accumulation in sub-surface horizons is relatively slow, certain of the data suggest that the rate of penetration can be increased by applying fertilizer in a few heavy doses rather than in numerous smaller doses.

In this connection comparison 9 is of special interest. Although this grove is about 10 years old, the soil received little, if any, fertilizer up to 3½ years ago. At this time, however, a program of varied and fairly heavy fertilization was inaugurated. Mixed commercials, manure, and various hay materials have constituted the source of phosphorus. The soil, though moderately light in texture, contains considerable silt and clay in the surface and these constituents increase in the lower horizons. Inspection of the data reveals that there is definite evidence of movement at least below 24 inches.

Another case where marked penetration has occurred in a medium-textured soil is recorded under comparison 11. Three annual applications of double superphosphate had been made up to the time of sampling. These treatments were applied to a small basin surrounding the palm tree; hence the rate of application has been heavy. Irrigation water in excess of 80 acre-inches per year has been supplied. The data show a marked movement of phosphorus which has proceeded at least into the third foot.

A third example of pronounced movement of phosphate from one heavy application of treble superphosphate is recorded in the data of comparison 20. This soil is moderately compact and has had not more than 6 or 7 irrigations from the time of fertilizer application to the time of sampling. As a result of this one dose, phosphate has penetrated at least into the third foot.

Waynick and Leavitt (5) have recently demonstrated the possibility of effecting considerable penetration of phosphate from ammonium phosphate by applying moderately large quantities of this fertilizer in solution.

With large applications of phosphate it is reasonable to believe that considerable downward movement might take place before diffusion and absorption processes are sufficiently complete to take the bulk of the phosphate out of solution, whereas, with equivalent amounts applied in smaller doses, fixation may be relatively more complete after each addition and hence permit of less penetration.

EFFECT OF FORM OF PHOSPHATE CARRIER

The heterogeneity of the field data presented permits little to be said regarding the comparative rates of movement of phosphorus fertilizers and the factors affecting this rate. A few points are deserving of mention, however.

The data on the bone meal plats of the Citrus Experiment Station Experiments (comparison 1) provided striking evidence of the lack of movement of the phosphorus in this material. These results are without doubt to be accounted for by the low water solubility of this material. It is reasonable to believe that similar results might be expected with other relatively insoluble phosphate fertilizers. However, the addition of physiologically acid or basic fertilizers, or organic materials in conjunction with these phosphate carriers, might materially alter their solubility and perhaps affect the rate of phosphorus movement. Furthermore, it is not inconceivable that insoluble phosphate in colloidal form might be carried mechanically by soil moisture into subsurface horizons.

Another point of interest is relative to the penetration of phosphate in soils in which a part or all of the phosphate has been applied in the form of manure. The figures on the manure plat of the Citrus Experiment Station fertilizer trial show definite evidence of phosphate movement into at least the third foot. Since this fertilizer has constituted the only source of phosphate applied to this soil, it indicates that the phosphate in manure must be relatively soluble, or that the rate of movement of phosphate is increased through some effect of organic matter in the soil. It may be that manure contains some soluble organic phosphate compound which is not as readily fixed as inorganic phosphate and hence moves more readily with soil water. With the exception of comparison 13, it will be noted that in every comparison in which manure has been the partial or sole source of phosphate applied, positive evidence exists of phosphate movement below the first foot.

Dyer (2) has presented data on some Rothamsted fertilizer plats which show that phosphate penetration has been especially marked in a manured plat as compared with those receiving inorganic phosphate. Blair and Prince (1) have also reported data in which there appears to have been a greater penetration of phosphate in manured plats than in those receiving superphosphate.

The preliminary results of the cylinder study on the comparative rates of movement of ammonium phosphate and triple superphosphate are recorded in Table 2. The soil is a loam, moderately compact, low in organic matter, carbonate free, and slightly alkaline in reaction.

TABLE 2.—*Comparative rate of penetration of Ammo-phos and triple superphosphate in a field soil.*

Days between treatment and sampling	Acre-inches of water applied up to date of sampling	Horizon, inches	Water-soluble PO_4 in p.p.m. of soil		
			No treatment	Ammo-phos	Triple superphosphate
55	6.65	0–4	21.3	45.7	64.7
		4–7	22.4	44.5	43.8
		7–10	27.3	22.2	34.4
		10–13	29.2	23.8	29.8
83	9.90	0–4	22.3	48.3	59.0
		4–7	19.8	36.0	35.6
		7–10	25.5	24.8	30.4
		10–13	24.0	18.7	29.7

After a period of 55 days from the date of incorporating the fertilizers, during which time the soil had received a total amount of water from irrigation and precipitation corresponding to a rate of 6.65 acre-inches, the first set of samples was removed.

In both the Ammo-phos and triple superphosphate treated soils there is definite evidence of phosphorus penetration into the 4 to 7 inch horizon, and in the case of the triple superphosphate some evidence of movement into the next horizon. The figures recorded are averages of the duplicate treatments.

At the end of 83 days, during which time an additional rain of 3.25 inches had fallen, another set of samples was removed from a second set of cylinders. These results indicate that there has been no further penetration of phosphate, nor apparently any enrichment of phosphate in the 4 to 7 inch zone. There is some slight evidence that a decrease in solubility of the phosphate has occurred during the period of 28 days intervening between the first and second sampling. Another interesting observation is that, although equivalent quantities of the two phosphates were applied, the solubility of the triple superphosphate remains higher than that of the ammonium phosphate.

In view of the preliminary nature of the data secured thus far and the fact that only one soil is being dealt with, it is unsafe to draw any very definite conclusions as to possible differences of behavior between the two fertilizers.

SURFACE ACCUMULATION OF PHOSPHATE

One of the important facts brought out by the field data is the marked accumulation of phosphate in the 0 to 6 and 6 to 12 inch horizons of nearly all of those soils which have been fertilized for any

length of time. This accumulation is in most cases greatest in the first 6 inches. In citrus, as well as all other orchards where cultivation is practiced, root development in this zone is obviously inhibited. Except in so far as the phosphate tied up in this zone acts as a potential reservoir from which the lower horizons are kept supplied, it is for all direct purposes a total loss to the tree. The inefficiency and wastefulness of the prevailing methods for applying phosphates to trees and deep-rooted crops is clearly demonstrated by these data. The need is therefore emphasized for a thorough and comprehensive study of possible means by which phosphate fertilizer can be efficiently and economically incorporated into the particular soil horizons where most needed.

FACTORS AFFECTING PHOSPHATE MOVEMENT

The agencies involved in the movement of phosphorus are soil water, plants, and soil organisms. It is generally believed that plants bring about a gradual translocation of phosphorus from the subsurface to the surface horizons, and under conditions of soil management in which crops are grown for green manure it is conceivable that this movement might be rather rapid.

Biological activity (micro and macro) probably plays an important part in phosphorus transformations in soils, and therefore would be expected to exert considerable influence on phosphate movement. Dyer (2) has called attention to the possible rôle of earthworms in the movement of phosphorus, and mentions that the marked penetration of phosphorus in the Rothamsted plat receiving manure may have been brought about by the activities of worms.

If attention is confined only to the agency of soil water, several points are apparent. The *direction* of movement will be governed by that of water movement. The *form* in which phosphate is carried need not necessarily be that of inorganic phosphate in true solution. Soluble organic forms, as well as inorganic and organic colloidal forms, might move readily with soil water. The *rate* of movement of soluble inorganic forms will probably be governed largely by the fixing power of the soil for such forms, the relative solubility of such fixed compounds, and the rate of water movement in soils.

Any fertilizer, amendment, or cultural practice which alters the solubility of soil phosphorus and the phosphorus-fixing power of soils, the rate of water movement in soils, the activities of soil organisms, and the growth of plants will manifestly influence the rate of phosphorus movement in soils.

SUMMARY

Water and acid extracts of soils which had received from 1 to 30 or more annual applications of a phosphate-carrying fertilizer compared with similar soils which had not received phosphate showed appreciable penetration of the phosphate below the surface foot in light- to medium-textured soils. Little or no penetration was found to have taken place in very heavy soils.

There are indications that a more rapid penetration of phosphorus is effected through a few heavy applications of phosphorus rather than more numerous lighter doses.

Comparisons of the relative penetration of phosphate from bone meal, superphosphate, and manure disclosed several important results. After 22 annual applications there was no evidence of phosphate penetration below 12 inches in plats receiving bone meal, as compared with marked penetration in plats receiving superphosphate and manure. There are indications that the phosphorus in manure moves readily through the soil or else some effect of organic matter facilitates the more rapid penetration of phosphorus.

In nearly all of the soils receiving phosphate over a period of years there has been a marked accumulation in the surface 6 to 12 inches.

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CHEMICAL NATURE AND SOLUBILITY OF AMMONIATED SUPERPHOSPHATES AND OTHER PHOSPHATES[1]

K. D. JACOB and W. H. ROSS[2]

The most significant recent development of immediate practical importance to the fertilizer industry is the treatment of superphosphate with ammonia, either in the form of the anhydrous liquid or as aqueous solutions.

Although this is a new development from the domestic commercial standpoint, McDougall (16)[3], in 1873, patented the use of superphosphate for the absorption of ammonia from gases resulting from the destructive distillation of carbonaceous material and proposed the use of the product as a fertilizer. Similar processes were patented by Bolton and Wanklyn (4) in 1881, Grahn (9) in 1889, and Besemfelder (3) in 1901. These processes did not achieve commercial success, however, because of the action of superphosphate in absorbing from the gases not only ammonia but also compounds that were toxic to plants.

Several United States patents relating to the treatment of superphosphate with ammonia were issued to Willson and Haff (24) in 1912 to 1915, and at about the same time Gerlach (8), in Germany, carried out some investigations on the reactions occurring in the process. The work of Gerlach and Brioux (6) indicated that ammoniation of superphosphate did not decrease the fertilizer value of the latter material, despite the fact that a portion of the phosphoric acid was reverted to forms insoluble in neutral ammonium citrate solution. In 1924, the Compagnie de Saint-Gobain (7) patented and placed on the French fertilizer market ammoniated superphosphate under the trade name "Superam" (1, 17). At the same time the process was also being investigated in Denmark (2). The process was not used on an extensive commercial scale in the United States, however, until 1928, when cheap synthetic ammonia became available in large quantities.

The rapid growth of the domestic production of ammoniated superphosphate is indicated by the fact that the quantities of

[1]Contribution from the Fertilizer and Fixed Nitrogen Investigations, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Presented before the Division of Agronomy at the 32nd Annual Convention of the Association of Southern Agricultural Workers, Atlanta, Georgia, February 4 to 6, 1931. Received for publication March 24, 1931.

[2]Chemist and Senior Chemist, respectively.

[3]Reference by number is to "Literature Cited," p. 786.

anhydrous and aqueous ammonia used for this purpose in 1928, 1929, and 1930 are estimated at 3,000, 25,000, and 40,000 short tons of nitrogen, respectively, practically the entire quantity being produced by the various synthetic ammonia processes. The production of synthetic ammonia in this country in 1928 and 1929 amounted to approximately 26,000 and 84,000 tons[4] of nitrogen, respectively. These figures indicate that approximately 11.5% and 30% of the respective 1928 and 1929 domestic productions of synthetic ammonia were used in the manufacture of ammoniated superphosphate. According to Brand (5), approximately 145,000 tons and 170,000 tons of nitrogen in the form of anhydrous and aqueous ammonia and ammonium salts were used for domestic fertilizer purposes in 1928 and 1929, respectively, practically the entire quantity being used in mixed fertilizers. Consequently, it seems that during these two years approximately 2% and 14.5%, respectively, of the ammoniacal nitrogen used in mixed fertilizers was supplied in the form of ammoniated superphosphate. A still greater proportion of nitrogen was supplied in this form in 1930 and there is reason to believe that the future will see even larger increases in the use of anhydrous ammonia for the treatment of superphosphate.

ECONOMIC ADVANTAGES OF AMMONIATED SUPERPHOSPHATE

Treatment of superphosphate with ammonia is of economic importance for several reasons, *viz.*, (a) anhydrous ammonia is the cheapest form of nitrogen available to the fertilizer industry; (b) ammoniation greatly improves the mechanical condition and the drilling and storing qualities of superphosphate and mixed fertilizers containing superphosphate; (c) it greatly reduces the rotting of fertilizer bags; (d) it provides a means for the fixation of significant quantities of ammonia with minimum dilution of the superphosphate, which is of considerable importance for the use of ordinary superphosphate in the preparation of high-grade fertilizer mixtures; (e) a considerable reduction in the quantity of sulfuric acid used in the manufacture of fertilizer materials may be effected by the substitution of free ammonia for ammonium sulfate as a source of nitrogen in mixed fertilizers; and (f) the time required for the curing of superphosphate may be shortened greatly by acidulating the phosphate rock with an excess of sulfuric acid and treating the product with ammonia.

[4]Estimated by P. E. Howard, Fixed Nitrogen Research Laboratory, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture.

Average domestic wholesale unit prices of nitrogen in several important fertilizers in January, 1928, 1929, 1930, and 1931 are given in Table 1.

TABLE 1.—*Wholesale prices of various forms of nitrogen.**

Nitrogen material	Average price per unit of nitrogen			
	Jan. 10, 1931	Jan. 11, 1930	Jan. 12, 1929	Jan. 7, 1928
Anhydrous ammonia...	$1.37†	$1.46†¶	——	——
Ammonium sulfate‡...	1.66	2.05	$2.24	$2.39
Calcium cyanamid§....	1.70	2.00	2.31	2.12
Sodium nitrate‖.......	2.63	2.74	2.82	3.08
Tankage, 10 and 15%, Chicago............	2.50	3.50	4.17	3.84
Cottonseed meal, 41%, Memphis**.........	3.85	5.64	6.86	6.55
Dried blood, domestic bulk, 15 to 17% ammonia, New York...	3.65	4.74	5.71	6.08

*Majority of figures compiled from data supplied by the National Fertilizer Association.

†Delivered in tank cars containing 50,000 lbs.

‡20.5% nitrogen.

§20.5 to 23.5% nitrogen.

‖15.6% nitrogen.

**Protein content.

¶Average price during 1930.

The figures show that anhydrous ammonia is today the cheapest form of nitrogen on the fertilizer market,[5] the price per unit of nitrogen being $1.37, or 29 cents less than nitrogen in the form of ammonium sulfate, the next cheapest source. It will be noted that the price of nitrogen in the form of ammonium sulfate has declined steadily during the past 3 years which is no doubt partly due to the competition arising from the use of uncombined ammonia in the manufacture of ammoniated superphosphate.

The mechanical condition of superphosphate is greatly improved by treatment with ammonia. For instance, angle of repose (18) measurements on 49 samples of the usual types of ordinary superphosphate gave values[6] ranging from 38.9° to 46.6° with an average of 43.6°, while 5 samples of ammoniated superphosphate gave values ranging from 36.7° to 37.25° with an average of 37.0°. Mehring and Cumings (19) have shown that the drillability of fertilizers decreases with increase in the angle of repose.

[5]The situation has changed since this paper was written. The *Oil, Paint and Drug Reporter* for Sept. 21, 1931, quotes anhydrous ammonia in 50,000-pound tank cars at $1.37 per unit of nitrogen, whereas domestic ammonium sulfate is quoted at $1.27 per unit of nitrogen and imported ammonium sulfate at $1.12 per unit.

[6]Unpublished data kindly furnished by A. L. Mehring, Concentrated Fertilizer Investigations, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture.

The rotting of fertilizer bags, which is a source of considerable expense and annoyance to the manufacturer, dealer, and farmer, is due largely to the presence of free phosphoric acid, hydrofluosilicic acid, and acid salts in the superphosphate. Bag rotting can be almost completely eliminated by the treatment of superphosphate and mixed fertilizers containing superphosphate with ammonia.

Ammonium sulfate containing approximately 20.5% nitrogen and potassium chloride containing approximately 50% potash are the highest grade nitrogen and potash materials commonly used in the fertilizer industry. The usual grade of ordinary superphosphate contains approximately 18% available phosphoric acid and the average grade of mixed fertilizer at present contains nitrogen, phosphoric acid, and potash in the approximate ratio of 3.5–10–4. The highest grade mixture that can be made from these materials when used in the above ratio will contain approximately 21.7% total plant food, or 4.3% nitrogen, 12.4% phosphoric acid, and 5.0% potash. If, however, ammoniated superphosphate containing 4.5% nitrogen and 17% available phosphoric acid is used, mixtures containing approximately 24.6% total plant food, or 4.9% nitrogen, 14.1% phosphoric acid, and 5.6% potash can be prepared from these materials. This increase of 3% in total plant food content is important because it enables the manufacturer to prepare a fertilizer mixture containing approximately 25% of plant food without the use of the more expensive concentrated phosphates, such as ammonium phosphate and triple or double superphosphate.

Ammonium sulfate is the principal ammonium salt used in mixed fertilizers, 445,000 short tons containing approximately 91,000 tons of nitrogen being used for this purpose in the United States during 1929. This quantity of ammonium sulfate required approximately 513,000 tons of 50° Bé. sulfuric acid for its manufacture. It seems very likely that further developments in the manufacture of ammoniated superphosphate will result in a marked decrease in the production of ammonium sulfate and consequently will result also in a corresponding reduction in the quantity of sulfuric acid used in the manufacture of fertilizer materials.

Careful proportioning of the sulfuric acid and phosphate rock is necessary in the manufacture of superphosphate in order to obtain a product that will cure properly and have a satisfactory mechanical condition and yet contain a minimum of citrate-insoluble phosphoric acid. If a sufficient excess of sulfuric acid is used to give a low content of insoluble phosphoric acid in the freshly made super-

phosphate, the material does not cure properly and does not acquire a satisfactory mechanical condition. Consequently, in order to obtain a satisfactory product having a minimum content of insoluble phosphoric acid, it is usually necessary to allow the superphosphate to cure on the pile for at least four weeks. This necessarily involves the use of considerable factory space which is a very important item in many plants. A superphosphate of excellent mechanical condition and low insoluble phosphoric acid content may be obtained in the minimum time, however, by treating phosphate rock with an excess of sulfuric acid and ammoniating the freshly made material. The excess of acid hastens the decomposition of the phosphate rock and also serves for the fixation of additional quantities of ammonia.

MANUFACTURE OF AMMONIATED SUPERPHOSPHATE

The ammoniation of superphosphate or mixed fertilizers containing superphosphate is a comparatively simple operation and does not usually require the services of skilled operators. The simplicity of the process has no doubt contributed to its rapid adoption by the fertilizer industry.

Until recently it was the general practice to treat the superphosphate or superphosphate mixtures with ammonia in the form of 25 to 30% aqueous solutions. For this purpose the anhydrous liquid ammonia is usually received at the fertilizer plant in steel tank cars containing 25 tons. It is made up into concentrated ammonia liquor as it is unloaded from the tank cars and is stored in this form until used. In the ammoniation of superphosphate or superphosphate mixtures the desired quantity of ammonia liquor is sprayed into the fertilizer where the ammonia is fixed by chemical reaction with the superphosphate. The process is usually carried out in 0.5- to 1.0-ton batch mixing machines of the types ordinarily used for the dry mixing of fertilizers.

Approximately 2 to 3% of ammonia, in the form of a 25 to 30% aqueous solution, may be added in this way to ordinary superphosphate, or its equivalent in a mixed fertilizer, giving a product of excellent mechanical condition without the formation of significant quantities of citrate-insoluble phosphoric acid. The reaction between the superphosphate and ammonia is very rapid and in plant practice the time required for ammoniation, mixing, and discharging the mixer is usually about 2 minutes. Loss of ammonia during the operation is negligible and the product is delivered from the mixing machine in a dry granular condition.

The quantity of ammonia in the form of a 25 to 30% solution that can be added to ordinary superphosphate, or its mixtures with

other fertilizer materials, is limited to a maximum of about 2 to 3%. Addition of greater quantities gives a product of poor mechanical condition because of the excessive amount of water present. Ordinary superphosphate, or its equivalent in a mixed fertilizer, may be treated directly, however, with anhydrous liquid ammonia to give a dry product of excellent mechanical condition, containing, under conditions of commercial operation, a maximum of 6 to 7% of ammonia. The direct use of anhydrous liquid ammonia seems to be growing in favor in the fertilizer industry and it is probable that it will largely displace aqueous ammonia provided certain proposed changes in the official method for the determination of available phosphoric acid are adopted. Anhydrous liquid ammonia is used in the ammoniation process in much the same way as aqueous ammonia. Storage of liquid ammonia at the fertilizer plant is avoided by using it direct from the tank car in which it is shipped. According to Keenen (15), there is no difference in the chemical behavior of anhydrous and aqueous ammonia towards superphosphate.

CHEMICAL REACTIONS IN THE AMMONIATION OF SUPERPHOSPHATE

Ordinary superphosphate is composed of a mixture of about 50% calcium sulfate ($CaSO_4$) and 25% monocalcium phosphate ($CaH_4(PO_4)_2$), with small quantities of other phosphates, water, silica, fluorine, and iron and aluminum compounds. The principal reactions (15) that occur when this material is treated with either anhydrous or aqueous ammonia under commercial conditions can be represented with a fair degree of certainty by the following equations.

Addition of 2% ammonia to the average superphosphate results in the formation of water-soluble monoammonium phosphate and citrate-soluble dicalcium phosphate, according to the equation

$$CaH_4(PO_4)_2 + NH_3 \longrightarrow NH_4H_2PO_4 + CaHPO_4 \qquad (1)$$

The manner in which the ammonia is added and the subsequent treatment of the product do not influence this reaction and no loss of available phosphoric acid occurs.

When 2 to 6% ammonia is rapidly added and no control of moisture and temperature conditions is maintained (conditions of commercial operation), several reactions occur simultaneously. Up to an addition of 4 to 4.5% ammonia the first major reaction apparently results in the conversion of the citrate-soluble dicalcium phosphate formed in reaction 1 into less soluble tricalcium phosphate by reaction with calcium sulfate and ammonia, according to the equation

$$2CaHPO_4 + CaSO_4 + 2NH_3 \longrightarrow Ca_3(PO_4)_2 + (NH_4)_2SO_4 \qquad (2)$$

With further addition of ammonia, the monoammonium phosphate formed in reaction 1 is converted into dicalcium phosphate by reaction with calcium sulfate and ammonia, as follows

$$NH_4H_2PO_4 + CaSO_4 + NH_3 \longrightarrow CaHPO_4 + (NH_4)_2SO_4 \quad (3)$$

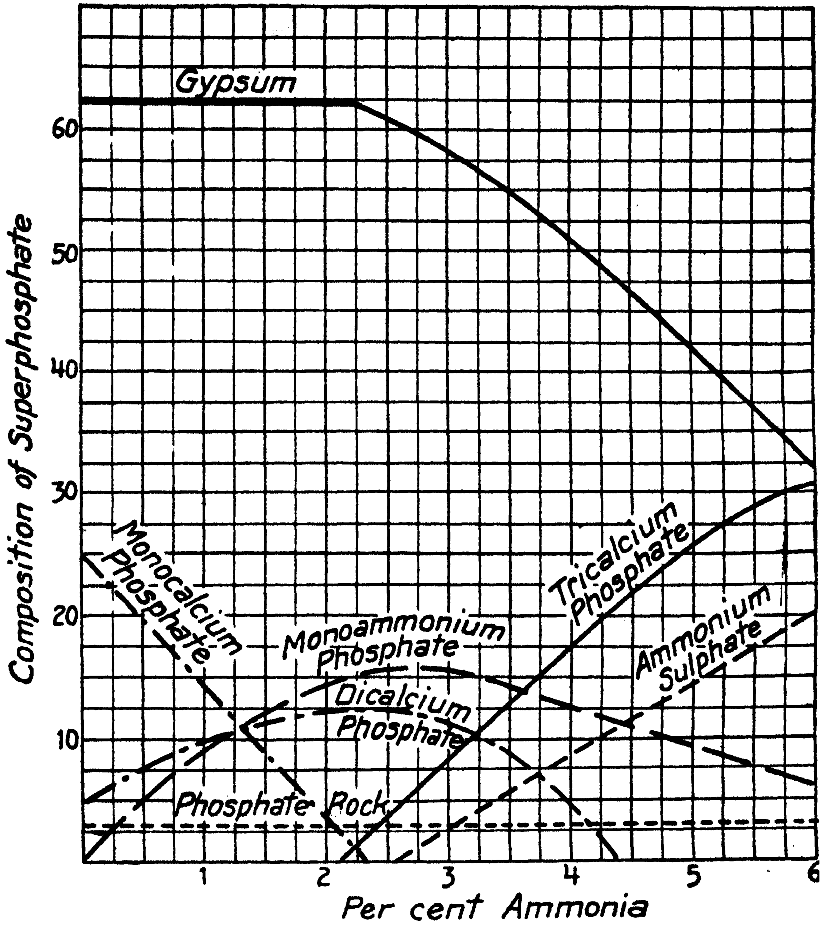

FIG. 1.—Change in composition of Florida pebble superphosphate caused by ammoniation.

The dicalcium phosphate so formed may subsequently react as in equation 2. Finally, the principal reactions occurring in heavily ammoniated superphosphate may be combined into one composite reaction represented by equation 4.

$$CaH_4(PO_4)_2 + 2CaSO_4 + 4NH_3 \longrightarrow Ca_3(PO_4)_2 + 2(NH_4)_2SO_4 \quad (4)$$

The graphs shown in Fig. 1 were constructed by Keenen (15) and represent the changes occurring in the composition of a Florida

pebble superphosphate as a result of the addition of progressively increasing quantities of ammonia.

Several reactions are also involved in the ammoniation of triple superphosphate, containing 40 to 50% available phosphoric acid the greater portion of which is present as monocalcium phosphate. These may be represented by equations 5, 6, and 7.

$$CaH_4(PO_4)_2 + NH_3 \longrightarrow CaHPO_4 + NH_4H_2PO_4 \quad (5)$$

$$CaH_4(PO_4)_2 + 2NH_3 \longrightarrow CaHPO_4 + (NH_4)_2HPO_4 \quad (6)$$

$$3CaH_4(PO_4)_2 + 8NH_3 \longrightarrow Ca_3(PO_4)_2 + 4(NH_4)_2HPO_4 \quad (7)$$

Triple superphosphate does not contain a significant quantity of calcium sulfate and consequently reactions 2, 3, and 4 which occur in the ammoniation of ordinary superphosphate take place to a negligible extent. In the commercial ammoniation of triple superphosphate reactions 5 and 6 are the principal ones that occur, it being possible to add 8 to 10% of ammonia without the formation of significant quantities of citrate-insoluble phosphoric acid.

TABLE 2.—*Citrate-insoluble phosphoric acid in ammoniated superphosphates.*

Ammoniated superphosphate prepared from	P_2O_5						NH_3 %
	Citrate insoluble				Water insoluble %	Total %	
	0.5-gram sample, %	1.0-gram sample %	1.5-gram sample %	2.0-gram sample %			
Florida pebble superphosphate........	1.02	1.70	2.67	3.66	11.03	18.67	5.76
Florida pebble superphosphate........	2.95	5.01	6.24	7.15	13.67	19.54	4.97
Tennessee brown-rock superphosphate....	0.33	1.11	2.55	3.76	11.38	19.25	4.35
Tennessee brown-rock triple superphosphate.......	1.11	1.41	1.61	1.88	25.41	44.96	7.51

CITRATE SOLUBILITY OF AMMONIATED SUPERPHOSPHATE

As pointed out previously, addition of 2 to 3% of ammonia to ordinary superphosphate or its mixtures with other fertilizer materials does not result in the formation of significant quantities of citrate-insoluble phosphoric acid. With larger quantities of ammonia the citrate-insoluble phosphoric acid increases, however, more or less in proportion to the quantity of ammonia added, which

is due to the formation of increasing quantities of tricalcium phosphate.

Howes and Jacobs (10) have shown that the values obtained for citrate-insoluble phosphoric acid in highly ammoniated superphosphates vary with (a) the weight of sample taken for analysis, (b) the acidity of the ammonium citrate solution, and (c) the time of digestion. The change in solubility with the weight of sample is of special significance in this determination. Thus, the value obtained for citrate-insoluble phosphoric acid in a highly ammoniated superphosphate may be decreased 50% or more by reducing the weight of sample from 2 grams, as required by the present official method, to 1 gram. Figures showing the effect of the weight of sample on the content of citrate-insoluble phosphoric acid in highly ammoniated ordinary and triple superphosphates (12) are given in Table 2.

The average mixed fertilizer contains about 50% of superphosphate and the quantity of this material in a 2-gram sample of such a mixture will only amount to about 1 gram. When the phosphoric acid is supplied in the form of ammoniated superphosphate, analysis of a mixed fertilizer will show a lower ratio of citrate-insoluble to total phosphoric acid than that found in the original ammoniated superphosphate and the ratio will change in proportion as the ammoniated superphosphate in the mixture is changed.

Vegetative tests (21) made at several experiment stations during the season of 1930 indicate that the citrate-insoluble phosphoric acid in highly ammoniated superphosphates, as determined by the present official method, has a true availability of about 75 as compared to 100 for monocalcium phosphate. This is in agreement with the known availability of other phosphatic materials of similar solubility.

It would thus seem that the present official method for measuring the availability of phosphates not only gives varying results with the proportion of ammoniated superphosphate in the mixture, but also gives values in the analysis of such materials which are not in good agreement with the results of vegetative tests. It has been proposed, therefore, to change the official method so that it will better evaluate ammoniated superphosphates and certain other phosphatic materials. The proposed change (21) involves reducing the sample from 2 grams to 1 gram and increasing the time of digestion from 0.5 hour to 1 hour. The adoption of such a change would provide for a marked increase in the quantity of ammonia that may be added to superphosphate.

CITRATE SOLUBILITY OF TRICALCIUM PHOSPHATE, BONE, BASIC SLAG, AND PHOSPHATE ROCK

The ammonium citrate test was devised originally as a laboratory method for differentiating between the readily available, water-insoluble phosphates, such as dicalcium phosphate, and the supposedly more slowly available materials, such as bone, precipitated tricalcium phosphate, ground phosphate rock, etc. The method was not supposed to be applicable to basic slag and for many years this material has been evaluated on the basis of its solubility in 2% citric acid solution. Thus far no satisfactory laboratory method has been devised for the evaluation of the phosphoric acid in bone, precipitated tricalcium phosphate, and ground phosphate rock.

Many vegetative tests have shown conclusively that the phosphoric acid in bone fertilizer is much more readily available than that in raw phosphate rock, and bone materials are in considerable demand for the fertilization of certain types of crops. Both of these materials are sold, however, on the basis of their total phosphoric acid content. Heretofore, precipitated tricalcium phosphate has not been a factor in the fertilizer industry and comparatively little data on its agronomic value are available. This material is now coming into a position of considerable importance because of its occurrence in highly ammoniated superphosphates and the difficulties in the matter of the laboratory evaluation of these materials are due principally to its presence. Consequently, a thorough study of its properties and fertilizer value is very desirable.

Recent investigations (13) in the Bureau of Chemistry and Soils have brought out some interesting facts regarding the solubility of tricalcium phosphate, bone, basic slag, and phosphate rock in neutral ammonium citrate. The official method for the determination of citrate-insoluble phosphoric acid was used in this work, the only variation being in the weight of sample taken for analysis.

The results given in Table 3 show a rather remarkable similarity in the citrate solubilities of tricalcium phosphate, bone meal, and basic slag. The percentage of the total phosphoric acid dissolved from these materials by 100 cc of citrate solution is affected to a marked extent by the weight of sample taken for analysis, particularly when the sample is decreased from 1.0 gram to 0.5 gram. It will be noted that these figures, in general, show a gradual increase in going from tricalcium phosphate to basic slag, the maximum difference being, however, only about 20%. On the other hand, the actual weights of phosphoric acid dissolved by 100 cc of citrate solution, in general, tend to decrease in going from tricalcium phosphate to basic

TABLE 3.—*Citrate solubility of di- and tricalcium phosphates, ammoniated superphosphate, bone, basic slag, and phosphate rock.*

Material*	Total P_2O_5 %	Citrate-soluble P_2O_5 as percentage of total P_2O_5				Mg P_2O_5 dissolved by 100 cc of citrate solution			
		0.5-gram sample	1.0-gram sample	1.5-gram sample	2.0-gram sample	0.5-gram sample	1.0-gram sample	1.5-gram sample	2.0-gram sample
Dicalcium phosphate†	46.37	100	100	97.1	89.2	232	464	674	823
Ammoniated superphosphate‡	19.15	—	—	—	—	53	94	123	143
Tricalcium phosphate§	41.80	74.3	46.0	33.6	27.0	155	192	210	224
Steamed bone meal†	34.52	68.3	47.5	36.1	30.8	118	164	187	212
Raw bone meal‖	21.18	80.2	62.0	45.3	40.1	85	131	144	170
Basic slag†	21.21	88.0	69.3	53.7	44.4	94	148	173	192
Bone ash†	39.89	11.6	7.1	5.9	5.5	23	29	35	44
Phosphate rock**	32.97	9.1	5.9	—	3.8	15	20	—	25

*Ground to 100 mesh, except ammoniated superphosphate which was ground to 40 mesh.
†Average of 2 samples.
‡Average of 3 samples containing an average of 5.03% NH_3.
§Average of 5 samples.
‖One sample.
**Average of 7 samples.

slag. These differences are due not only to differences in the chemical constitution of the phosphates but to the presence of other compounds, particularly in basic slag, which are themselves soluble in citrate solution and consequently tend to reduce the solubilities of the phosphates.

The figures obtained on basic slag are of particular interest since they indicate that by decreasing the weight of sample it may be possible to obtain satisfactory results for available phosphoric acid in this material by the use of neutral ammonium citrate solution instead of the customary 2% citric acid solution. In fact, by reducing the weight of sample to 0.5 gram the figures obtained for citrate-soluble phosphoric acid approximated very closely those obtained for citric acid-soluble phosphoric acid as determined by the official method.

The results (Table 3) show that the solubilities of bone ash and ground rock phosphate are only slightly affected by the weight of sample taken for analysis. The solubility of the phosphoric acid in these materials is only about 10 to 20% of that in tricalcium phosphate, bone meal, and basic slag. The low solubility of bone ash is due apparently to changes in the chemical constitution of the phosphate as a result of ignition. Grinding phosphate rock to colloidal fineness does not increase its citrate solubility to a significant extent.

On the basis of citrate solubility alone it may be concluded that the comparative fertilizer value of the phosphoric acid in dicalcium phosphate, tricalcium phosphate, bone meal, basic slag, bone ash, and ground rock phosphate is approximately in the order named. It may be concluded further that tricalcium phosphate, bone meal, and basic slag are approximately of equal value as phosphatic fertilizers, while dicalcium phosphate has a higher value and bone ash and ground rock phosphate a much lower value. Agronomic experiments with these materials seem to confirm this conclusion.

CHEMICAL CONSTITUTION OF TRICALCIUM PHOSPHATE, BONE, BASIC SLAG, AND PHOSPHATE ROCK

Many chemists and agricultural workers seem to have the impression that the phosphoric acid in bone and phosphate rock is present principally as tricalcium phosphate, differing from precipitated tricalcium phosphate only in its physical condition. This impression, no doubt, results largely from the trade practice of expressing the grade of bone and phosphate rock in terms of tricalcium phosphate. Recently, this has caused considerable confusion, particularly as regards the chemical nature of the tricalcium phosphate formed when superphosphate is treated with ammonia.

Although the behavior of unignited bone towards citrate solution is quite similar to that of precipitated tricalcium phosphate, Shear and Kramer (23) state that there is no evidence to show the existence in bone of tricalcium phosphate ($Ca_3(PO_4)_2$) as such. As a result of x-ray investigations de Jong (14) concludes that bone is essentially a carbonate-phosphate, probably having the empirical formula $3Ca_3(PO_4)_2.CaCO_3$. The comparatively low citrate solubility of bone ash may be due to the formation of the oxy-phosphate upon ignition of the carbonate-phosphate, as follows

$$3Ca_3(PO_4)_2.CaCO_3 \longrightarrow 3Ca_3(PO_4)_2.CaO + CO_2.$$

Although phosphate rock usually occurs in the submicro-crystalline condition, recent x-ray investigations have shown that the chemical constitution of the various domestic types is essentially the same as that of macro-crystalline fluorapatite to which the empirical formula $3Ca_3(PO_4)_2.CaF_2$ is ascribed. It will be noted that the formula for apatite differs from that for bone only in that the carbonate radical in the latter is replaced by fluorine. All the commercial types of phosphate rock now produced in the United States contain 3 to 4% of fluorine (11, 20), the greater portion of which is no doubt combined with the phosphate to form a complex compound having the same empirical formula as fluorapatite. The comparatively low citrate solubility of phosphate rock seems to be due principally to the presence of this fluorine-phosphate compound.

Treatment of phosphate rock with sulfuric acid, as in the manufacture of superphosphate, results in the breaking up of the fluorine-phosphate complex, and the conversion of the phosphate into water- and citrate-soluble forms. Only about 25% of the fluorine, however, is volatilized from the superphosphate (11) during the manufacturing process, the rest remaining in the finished product principally as calcium fluoride and calcium fluosilicate. It has been suggested that formation of citrate-insoluble phosphoric acid in ammoniated superphosphates may be due partly to recombination of the fluorine and phosphate producing the same type of compound present in the original phosphate rock. A study (12) of the composition of citrate-insoluble residues obtained from superphosphates and ammoniated superphosphates indicates, however, that such a recombination does not occur.

The chemical constitution of fluorine-free basic slag is a disputed question. The earlier investigators were of the opinion that the phosphoric acid is combined principally as tetracalcium phosphate ($Ca_3(PO_4)_2.CaO$), but according to Russell (22) it is now generally believed in Great Britain that the phosphoric acid is present as

complex calcium silico-phosphates. The low citrate and citric acid solubility of the phosphoric acid in fluorspar basic slags is due to the presence of a calcium fluor-phosphate, similar to or identical with the compound present in phosphate rock.

FACTORS AFFECTING THE CITRATE SOLUBILITY OF TRICALCIUM PHOSPHATE

Recent investigations in the Bureau of Chemistry and Soils have shown that the solubility of pure tricalcium phosphate in neutral ammonium citrate solution is affected by a number of factors, the most important of which are weight of sample taken for analysis and presence of other water-insoluble compounds. The first of these factors has been the subject of considerable discussion in recent literature (10, 12, 13, 21) and has been dealt with at some length in the present paper. The importance of the second factor does not, however, seem to have been emphasized in any previous publication.

TABLE 4.—*Effect of other compounds on the citrate solubility of tricalcium phosphate.**

Added material	Citrate-soluble P_2O_5 as percentage of total P_2O_5
None	42.2
$CaSO_4.2H_2O$ (synthetic)†	25.1
$CaSO_4.2H_2O$ (natural)†	17.4
$CaCO_3$ (synthetic)†	16.3
$CaCO_3$ (high Ca limestone)†	14.8
Dolomite	31.9
CaF_2 (natural)†	27.9
$CaH_4(PO_4)_2.H_2O$	26.7
$CaCl_2.2H_2O$	23.8
$MgCO_3$ (synthetic)†	17.1
$MgSO_4.7H_2O$	34.9
Fe_2O_3†‡	29.9
Al_2O_3†‡	32.7

*1 gram $Ca_3(PO_4)_2$ containing 40.86% total P_2O_5 + 1 gram of other material.
†Ground to 100 mesh.
‡Freshly precipitated material dried at a temperature below 100°C.

The results given in Table 4 show that calcium salts in general depress the citrate solubility of tricalcium phosphate to a marked extent. Magnesium salts and precipitated iron and aluminum oxides also have a pronounced depressing effect. Dolomite, however, has a much smaller effect than either calcium or magnesium carbonate. The effect of gypsum and calcium carbonate is of particular importance since ammoniated superphosphate always contains large quantities of calcium sulfate and calcium carbonate in the form of ground limestone is frequently added to mixed fertilizers. These compounds are not removed by washing with water prelimin-

ary to the citrate digestion. The importance of removing the water-soluble calcium phosphate prior to the citrate digestion is indicated by the fact that mono-calcium phosphate depresses the solubility of tricalcium phosphate to a significant extent. To a less extent, these salts also depress the citrate solubility of dicalcium phosphate.

The results show that the citrate solubility of tricalcium phosphate in a mixed fertilizer may be considerably lower than that of the pure salt. The decrease in solubility is not due to any change in the chemical nature of the calcium phosphate but simply to the effect of other compounds in depressing its solubility.

SUMMARY

During the past 3 years treatment of superphosphate, or fertilizer mixtures containing superphosphate with ammonia, either in the form of the anhydrous liquid or as aqueous solutions, has become an important operation in the fertilizer industry.

The process is important because (a) anhydrous ammonia is one of the cheapest forms of nitrogen available to the fertilizer industry; (b) ammoniation reduces the rotting of fertilizer bags and greatly improves the mechanical condition and the drilling and storing qualities of fertilizer mixtures; (c) it permits the preparation of balanced mixtures containing as much as 25% of plant food without the use of the higher priced concentrated fertilizer materials; and (d) the time required for the curing of superphosphate may be shortened greatly by acidulating phosphate rock with an excess of sulfuric acid and treating the product with ammonia.

The chemical reactions occurring during the ammoniation of superphosphate depend upon the quantity of ammonia used. Addition of 2% of ammonia to ordinary superphosphate results in conversion of the water-soluble monocalcium phosphate into citrate-soluble dicalcium phosphate and water-soluble monoammonium phosphate. When greater quantities of ammonia are used an increasingly large portion of the phosphoric acid is converted into the difficultly soluble tricalcium phosphate.

Because of the presence of tricalcium phosphate, the citrate solubility of the phosphoric acid in heavily ammoniated superphosphate varies with the weight of sample taken for analysis and the results obtained on such materials by the present official method are not in good agreement with the results of vegetative tests. It has been proposed to change the official method so that it will better evaluate ammoniated superphosphates and certain other phosphatic materials.

The proposed change involves reducing the sample from 2 grams to 1 gram and increasing the time of digestion from 0.5 hour to 1 hour.

As regards their solubilities in citrate solution, bone meal and basic slag are very similar to tricalcium phosphate which is an important constituent of heavily ammoniated superphosphate. The citrate solubility of these materials is affected to a marked extent by the weight of sample taken for analysis, but with a constant weight of sample almost the same weights of phosphoric acid and the same percentages of the total phosphoric acid are dissolved by 100 cc of neutral ammonium citrate solution.

The citrate solubility of the phosphoric acid in bone ash and ground phosphate rock is only 10 to 20% of that in tricalcium phosphate, bone meal, and basic slag, and the results are only slightly affected by the weight of sample taken for analysis.

Anhydrous tricalcium phosphate has the empirical formula $Ca_3(PO_4)_2$, while bone is essentially a carbonate-phosphate having the empirical formula $3Ca_3(PO_4)_2.CaCO_3$. Phosphate rock is a fluorphosphate, $3Ca_3(PO_4)_2.CaF_2$, differing from bone only in that the carbonate is replaced by fluorine.

The citrate solubility of tricalcium phosphate in a mixed fertilizer may be considerably lower than that of the pure salt because of the effect of other compounds, such as calcium carbonate and calcium sulfate, in depressing its solubility.

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THE MOVEMENT AND FIXATION OF PHOSPHATES IN RELATION TO PERMANENT PASTURE FERTILIZATION[1]

A. R. MIDGLEY[2]

Fertilizers on grasslands are usually applied as top dressings. The essential elements of these materials must move into the region of the feeding roots before they can be utilized. Because of these facts and also because of the fact that phosphates apparently move rather slowly in soils, it seemed desirable to study in detail the movement and fixation of phosphates, particularly with reference to pasture fertilization. The experiments reported here include a study of crop response from applications of superphosphate to the surface and at various soil depths, together with chemical analyses to determine the rate and extent of phosphate movement and fixation in soils.

Way (15),[3] as early as 1850, expressed certain ideas in regard to absorption of fertilizing materials. Weidemann (16) showed that both acid and basic muck soils fix phosphates. Schreimer and Failyer (11) concluded that the addition of large amounts of soluble phosphates did not materially increase the amount found in the soil solution.

Petit (10), working with soils containing large quantities of organic matter, found that they did not fix phosphates very readily, but when the organic matter was removed none of the phosphate remained soluble. He concluded that the fixation was due to the inorganic materials, such as calcium, aluminium, and iron compounds.

Harrison and Das (7), in India, applied soluble phosphates to soils and found that on the calcareous soils most of the phosphate is retained in the surface layers, while on the non-calcareous soils considerable penetration of phosphate takes place. They also found a very rapid reversion of the monocalcium phosphate to the tri-calcium phosphate on the calcareous soils.

[1]Abstract of a thesis submitted in partial fulfillment of the requirements for degree of doctor of philosophy at the University of Wisconsin, Departments of Agronomy and Soils. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication March 31, 1931.

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[3]Reference by number is to "Literature Cited," p. 798.

The investigations of Ellett and Hill (4) showed that the hydroxides of iron and aluminium fix 60 to 70% of the water-soluble phosphates and change them into relatively insoluble or unavailable forms, but when equal quantities of lime were added to these hydroxides only 43% was fixed as unavailable. Where only calcium or magnesium carbonate was used as the fixing agent, the resulting compounds were completely dissolved by weak acids.

Interesting work on the amount of phosphate fixation on Hawaiian soils was done by Crawley (2). In his first experiment over 7 tons of double superphosphate an acre were applied on the surface and given an immediate irrigation. The first inch of soil retained over one-half, the 3-inch depth over nine-tenths, and the 6-inch depth retained all the phosphate applied. When an interval of 15 hours existed before adding the water, the first inch retained over nine-tenths of the phosphate applied. In another series of experiments he tried to determine the total amount of phosphate which the soil was capable of fixing. A large excess of phosphate was mixed with the surface 6 inches of soil which was kept moist. After an interval of 1 day, an amount equal to fully 40 tons of superphosphate was fixed by the surface 6 inches of soil, and after 21 days this amount increased to 181 tons. Crawley claims that these soils are much more basic than the average American soil.

Van Alstine (14), working on the movement of plant food within the soil, concluded that phosphates usually remain where placed unless removed by crops or erosion. Alway and Rost (1), working with prairie soils, show that the phosphate content of these soils steadily decreases from the surface downward. This is further proof that phosphates do not move down readily.

Some workers have found that phosphates must be mixed with the soil in order to secure maximum results. Feilitzen (5), working with Swedish moor soils, found that Thomas slag, if mixed with the soil to a depth of 6 inches, increased the yield 42% over that obtained when the slag was harrowed into the surface inch. For orchards, Kelley (8) advised deep incorporation of fertilizers, especially phosphates and potash. He claims that these salts when applied on the surface could not possibly give maximum results.

Leachings from lysimeter tanks usually show only traces of phosphates. The results obtained by Dyer (3), Lyon and Bizzel (9), and others support this. Dyer, however, found an appreciable leaching of phosphates if accompanied by constant dressings of potash, sodium, or magnesium salts.

PLAN OF STUDY

The primary object of this work was to study the movement and fixation of phosphates in relation to pasture fertilization. The results obtained from the use of phosphatic fertilizers under field plat tests are given, together with plant response from different methods of applying superphosphate to pasture and other crop plants. The downward movement of phosphatic fertilizers was determined by chemical analysis of the soil at various depths and by controlled leaching experiments in the laboratory.

FIELD RESULTS FROM THE USE OF SUPERPHOSPHATE

Extensive fertilizer trials on bluegrass pastures have been conducted at the Wisconsin Experiment Station, but only the results obtained from the use of phosphatic fertilizers are presented here because the yields of dry matter produced have a direct relationship to the downward movement and fixation of phosphates.

The pasture consisted mainly of bluegrass (*Poa pratensis*) and white clover (*Trifolium repens*) growing on a Miami silt loam. In order to determine the variability and original fertility of the experimental plats, soil samples were taken from each plat before the fertilizers were applied. These samples were analyzed for readily available phosphorus according to the method described by Truog and Meyer (13). The available phosphorus content was found to be very low, ranging from 6 to 10 pounds per acre. The soil was also low in organic matter and had a pH of 6.6.

These fertilizer experiments were begun in the early spring of 1926 on 1/80th acre plats. Superphosphate was applied as a surface dressing at the rate of 300 pounds of 20% material. A second application of 300 pounds per acre was applied in the spring of 1927. The plats were harvested with a lawn-mower set so as to approximate average grazing by cattle. The total yields of dry matter produced each year for 3 consecutive years are given in Table 1.

TABLE 1.—*Yields of dry pasture grass in pounds per acre produced with and without superphosphate.*

Year	No treatment	Superphosphate 300 lbs. in 1926 and 300 lbs. in 1927	Increase %
1926	794.8	801.4	0.83
1927	782.4	834.2	6.62
1928	1,092.8	1,342.8	22.80
3-year average	890.0	992.8	11.50

Results presented in Table 1 show that the percentage increase in yield from the use of superphosphate is low the first 2 years. Even after the second year the increase was less than 7%. However, it should be noted that the percentage increase grew larger each year. This may have been due to the slow movement of the phosphate into the root region or to the encouragement of white clover and such other plants as may be better able to utilize the surface application of superphosphate. White clover having a stoloniferous rooting habit, sending out new roots at the very surface of the soil, may be better able to feed nearer the surface than bluegrass with underground rhizomes. No attempt was made to separate the grass from the clover, but repeated observations indicated a marked increase of the latter on the phosphated plats.

PLANT RESPONSE FROM DIFFERENT METHODS OF APPLYING SUPERPHOSPHATE

OLD BLUEGRASS PASTURE

In order to see what responses could be obtained on this same soil by working the phosphate into it, two small plats, each 3 feet by 1 rod, were laid out. On one of the plats the sod was sliced vertically with a knife to a depth of about 6 inches and at intervals of about 4 inches. An application of 600 pounds per acre of 20% superphosphate was made in the knife grooves and washed in with a small amount of water. On the other plat the superphosphate was applied as a surface dressing. The results are given in Table 2.

TABLE 2.—*Yields in grams of dry pasture grass per plat obtained by two different methods of applying superphosphate.*

Material harvested	Surface application of superphosphate	Application of superphosphate 6 inches deep	Increase of deep application over surface application %
Grass	410	645	57.32
Weeds (rag weed)	290	539	85.86
Total material	700	1,184	71.59

Data in Table 2 show rather strikingly the importance of working the phosphate into the soil. No doubt some response is obtained from a surface application, but it is not very likely that maximum results are immediately obtained.

NEW BLUEGRASS SEEDING

To study further the effects of mixing superphosphate to different soil depths, the following experiment was conducted in the green-

house (Fig. 1). Two-gallon jars were filled with a Miami silt loam taken from the University farm. This particular soil was chosen because field results had given no appreciable response from top dressings of superphosphate.

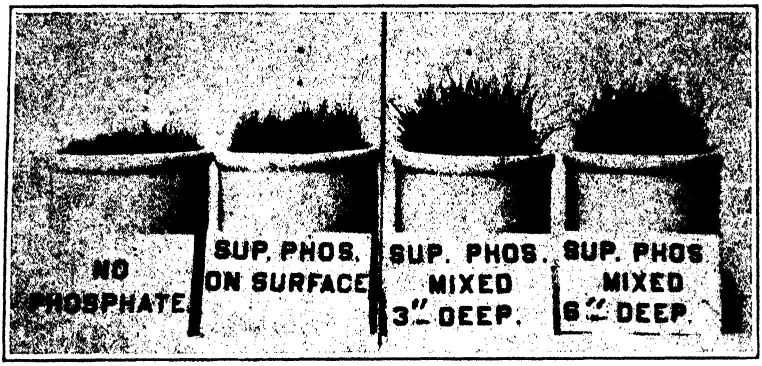

FIG. 1.—Responses by a new seeding of bluegrass to 300 pounds per acre of 20% superphosphate applied in different ways.

The phosphate application of 300 pounds per acre was made at three different depths, *viz.*, on the surface and at depths of 3 and 6 inches. After mixing the phosphate with the desired depth of soil, the mixture was moistened and the bluegrass seed planted. The experiment was run in duplicate and the weights given for each cutting are the average weights of the duplicate pots. The results are given in Table 3.

TABLE 3.—*Yields in grams of bluegrass grown in pots with phosphate added at different depths.*

Depth of phosphate treatment	Weight first cutting	Weight second cutting	Total weight	Increase over no treatment, %
Untreated	1.32	0.56	1.88	—
Surface application	2.21	0.55	2.76	46
Mixed 3 inches deep	3.65	1.36	5.01	166
Mixed 6 inches deep	3.22	1.46	4.68	149

These data show that the best yields were obtained by mixing the phosphate with the soil. The yields were greater with the 3-inch depth than with the 6-inch depth. This was probably because the 3-inch depth provided a greater concentration of the phosphate in the feeding area of the young plants and lessened fixation in difficultly available form.

CULTIVATED CROP PLANTS

Crop plants, including corn, sorghum, and sudan grass, were used in field plats to obtain additional information on the influence of mixing the phosphate with soil to various depths. Superphosphate was applied at the rate of 500 pounds per acre on the surface and then mixed to various depths. The soil had recently been plowed and prepared so that the additional working of the soil in the process of incorporating the phosphate probably had very little influence.

After mixing the phosphate thoroughly to the desired depths, three rows of each kind of seed were planted. Both corn and sorghum were planted in hills, while the sudan grass was drilled. The plats receiving the surface treatments were planted before the phosphate was applied so that the phosphate would not become mixed with the soil during the planting. The yields of dry matter for each treatment are given in Table 4.

TABLE 4.—*Comparative yields of corn, sorghum, and sudan grass with superphosphate applied at different depths.*

Depth of phosphate treatment	Corn		Sorghum		Sudan grass	
	Plat weight, lbs.	Increase over no treatment %	Plat weight, lbs.	Increase over no treatment %	Plat weight, lbs.	Increase over no treatment %
No treatment	7.5	——	4.5	——	5.6	——
On surface	8.0	6.6	4.3	0.0	7.6	35.6
Mixed ½ inch deep	9.0	20.0	7.0	55.5	9.4	67.8
Mixed 3 inches deep	19.0	153.5	12.0	166.5	12.6	125.0
Mixed 6 inches deep	27.1	262.0	9.5	111.0	12.2	118.0

These data show that surface applications gave practically no increase in yields with the exception of sudan grass. Since the latter was planted in drilled rows, the shading effect thus produced tended to keep the soil somewhat moist near the surface so that the roots were encouraged to feed closer to the surface. This was actually found to be the case after digging up several plants at the termination of the experiment.

PENETRATION OF SUPERPHOSPHATE UNDER FIELD CONDITIONS

Since the foregoing experiments indicated that the movement of phosphate into the soil is very slow, it seemed desirable to study more accurately the downward movement of phosphates under field conditions. Small plats were laid out on old pasture land and superphosphate applied at the rate of 300 and 600 pounds per acre. After various intervals of time, soil samples were taken at different depths from treated and untreated plats and the available phosphorus

determined on each sample according to the method of Truog and Meyer (13). The data from this experiment are presented in Table 5.

TABLE 5.—*Penetration of superphosphate on plats receiving 300 pounds and 600 pounds of 20% superphosphate per acre, phosphate applied April 25, 1928.*

Depth	Amount of soluble phosphorus in the soil		
	No treatment, p.p.m.	300-lb. rate, p.p.m.	600-lb. rate. p.p.m.
Plats Sampled June 25, 1928			
First ½ inch	12.2	80.0	155.0
Second ½ inch	4.8	6.0	18.0
Second inch	3.2	3.8	6.0
Third inch	3.0	3.4	3.4
Plats Sampled October 15, 1928			
First ½ inch	10.0	54.0	100.0
Second ½ inch	4.0	14.0	38.0
Second inch	3.6	5.0	8.0
Third inch	4.0	4.0	3.6

An examination of these data again show that most of the phosphate is retained within the surface inch even after an interval of 6 months. There is, however, a decided decrease in the total amount of available phosphorus within the 3-inch depth after an interval of 6 months as compared with the 2-month interval. The amounts taken up by plants during this period can not fully account for this difference, therefore part of the phosphorus must have gone into more difficultly soluble forms.

LEACHING EXPERIMENTS

In order to study in detail certain factors which influence the fixation of phosphates, controlled laboratory experiments were conducted. In some experiments the phosphates were applied on the surface of a given depth of soil and leached with a definite amount of distilled water. The leachings were then analyzed for phosphorus. Other experiments were designed to determine the amount of phosphate that would be fixed by a soil (rendered water insoluble) when the phosphate was thoroughly mixed with the soil and aged (alternately wet and dry).

Two soils, a Miami silt loam, slightly acid and low in organic matter, and Carrington silt loam, strongly acid and rather high in organic matter, were used.

COMPARATIVE MOVEMENT OF DIFFERENT PHOSPHATES THROUGH SOILS

Two hundred gram portions of soil, which gave approximately a ¾ inch depth, were placed in Buchner funnels having a diameter of

10.5 cm. A filter paper (S. & S. No. 589 blue ribbon) was placed on the bottom of each funnel. Four phosphatic materials, including commercial 20% superphosphate, commercial ammonium phosphate (Ammo-phos B), chemically pure di-potassium phosphate, and di-sodium phosphate, were compared. The phosphates were applied on the surface of the soil at a rate equivalent to 300 pounds per acre of 20% superphosphate.

The soil was then slowly leached with distilled water. The first 110 cc of leachate, which is roughly equal to ½ inch of water on this funnel, was kept separate. After this, three successive 250-cc portions of leachate were obtained. All of the leachings were analyzed for phosphorus and the results are given in Table 6.

TABLE 6.—*Extent of leaching of different phosphatic materials through a ¾ inch layer of soil.*

Kind of phosphate	Phosphorus in leachings				Total phosphorus leached, mg	Portion of total phosphorus removed, %
	First 110 cc, p.p.m.	Second 250 cc, p.p.m.	Third 250 cc, p.p.m.	Fourth 250 cc, p.p.m.		
			Miami Silt Loam			
Superphosphate....	0.19	0.40	1.80	1.72	1.00	3.94
Ammo-phos.......	4.00	5.56	7.87	7.20	5.59	22.00
Potassium phosphate...........	3.50	5.50	8.20	7.00	5.55	21.84
Sodium phosphate..	25.00	53.00	30.00	4.00	24.50	96.50
			Carrington Silt Loam			
Superphosphate....	0.00	0.00	0.00	0.00	0.00	0.00
Ammo-phos.......	0.05	0.09	2.30	1.00	0.852	3.36
Potassium phosphate...........	0.05	0.08	1.93	1.30	0.831	3.28
Sodium phosphate..	3.25	28.00	51.20	9.00	22.400	88.10

The results clearly demonstrate the slower movement of superphosphate as compared with the other phosphatic salts. This suggests that it may be desirable to use other phosphatic fertilizers than superphosphate when maximum penetration of the soil is desired from surface dressings.

INFLUENCE OF WETTING AND DRYING TREATMENTS ON THE FIXATION OF PHOSPHATES

In this experiment the influence of alternate wetting and drying treatments on the fixation of phosphates within a ¾ inch depth of soil was studied. The four phosphates mentioned in the previous experiment were thoroughly mixed with the required amount of soil. In some cases, the mixtures were kept moist until leached, while in

others, they were alternately wetted and then dried at room temperature with an electric fan. After these treatments, 200-gram samples were placed in Buchner funnels and leached with distilled water. The percentages of phosphorus removed in 110 cc of filtrate after each treatment are given in Table 7.

TABLE 7.—*Effects of wetting and drying treatments on the fixation of the phosphate in different phosphatic salts when mixed with soil as shown by percentage of phosphorus not fixed and removed in 110 cc of filtrate.*

Treatment	Percentage of phosphorus leached from soil			
	Super-phosphate	Ammo-phos	Potassium phosphate	Sodium phosphate
	Miami Silt Loam			
Leached immediately	3.51	12.20	11.00	88.40
Moistened 12 hours	1.73	6.50	5.20	44.40
Moistened 7 days	0.60	0.86	1.60	19.70
Moistened 65 days	0.22	0.60	0.65	17.80
Alt. wet and dry 2 times	0.28	0.51	0.80	18.40
Alt. wet and dry 4 times	0.15	0.32	0.43	12.80
Alt. wet and dry 6 times	0.08	0.22	0.24	9.52
Alt. wet and dry 8 times	0.06	0.19	0.20	8.22
Alt. wet and dry 16 times	0.03	0.08	0.10	5.20
	Carrington Silt Loam			
Leached immediately	1.30	1.41	1.73	52.00
Moistened 12 hours	0.86	0.71	1.02	29.20
Moistened 15 days	0.26	0.28	0.41	5.40
Alt. wet and dry 2 times	0.13	0.13	0.21	2.70
Alt. wet and dry 4 times	0.06	0.08	0.18	1.60

The results presented in Table 7 show a pronounced difference in the behavior of the different phosphates. The phosphate in superphosphate is fixed much more readily than that in the other phosphatic salts, while that in sodium phosphate is fixed least readily. The data also show that practically all of the phosphate can be converted into a form that is difficultly soluble in water by wetting and drying treatments. This can be expected because in drying the soil, the resultant solution becomes more concentrated and thus allows for a more rapid and complete chemical reaction to go on. This is important from a practical standpoint of pasture fertilization, because superphosphate is applied on the surface and is thus subjected to a large number of wetting and drying processes throughout the season. It would seem from these results that a heavy continuous rain immediately after applying the phosphate would result in a greater penetration of it into the soil than a similar amount of water in light, intermittent rainfalls. This may also explain in part the advisability of early spring applications of phosphate to grass lands.

INFLUENCE OF DIFFERENT FERTILIZING MATERIALS ON THE DOWNWARD MOVEMENT OF SUPERPHOSPHATE

Complete fertilizers usually consist of a mixture of salts with superphosphate. The following experiment was performed to ascertain what influence these added materials had on the downward movement of the superphosphate.

Commercial forms of sodium nitrate, ammonium sulfate, potassium sulfate, and hydrated lime were separately mixed with equal amounts of superphosphate. Each mixture was then applied on the surface of a ¾ inch layer of soil which was held on a Buchner funnel and slowly leached with distilled water. The first and second 110 cc of filtrate were analyzed for phosphorus. The results are presented in Table 8.

TABLE 8.—*Effect of various fertilizing materials on the downward movement of superphosphate in Miami silt loam.*

Fertilizer salts added	Phosphorus removed in leachates	
	First 110 cc, p.p.m.	Second 110 cc, p.p.m.
Superphosphate only	0.055	0.325
Superphosphate and $Ca(OH)_2$	None	None
Superphosphate and K_2SO_4	0.050	0.160
Superphosphate and $(NH_4)_2SO_4$	0.035	0.150
Superphosphate and $NaNO_3$	0.780	1.870

It is evident from these data that certain fertilizing salts have a considerable influence on the movement of superphosphate through Miami silt loam. Potassium and ammonium sulfate checked the movement of phosphate, while sodium nitrate greatly increased it. This may be explained, in part at least, by the action of these salts in replacing certain bases from the base exchange compounds of the soil. Potassium and ammonium are more active in this respect than sodium and thus have a tendency to replace calcium which is then free to form the more difficultly soluble tri-calcium phosphate. Since the base exchange compounds seem to have a greater affinity for ammonium and potassium than for sodium, there would be a tendency for more soluble phosphate to be formed whenever a sodium salt was used. Further work along this line is being studied by the author.

SUMMARY

A study was made of the movement of phosphates in soils, with special reference to pasture fertilization. The experiments included (a) field studies of the use of phosphatic fertilizers; (b) plant response from different methods of applying superphosphate to

grasslands and cultivated crops; (c) chemical analysis of soil taken at various depths to determine the movement of superphosphate under field conditions; (d) studies of the comparative movement and fixation of different phosphates under controlled laboratory conditions; and (e) studies of the influence of various fertilizing materials on the penetration of superphosphate.

These studies indicate that superphosphate when applied as a surface dressing moves downward very slowly. Most of the phosphate was found within the surface inch of soil even after an interval of 6 months.

Maximum results can not be obtained immediately unless the phosphate is thoroughly mixed with the soil. Superphosphate worked into an old-established bluegrass sod gave a total increase of 71.5% more than a similar amount of superphosphate applied on the surface.

There is a very marked difference in the behavior of different phosphatic salts as to their movement through soils. From a ¾ inch layer of Carrington silt loam held on a Buchner funnel, none of the phosphate in superphosphate was removed by leaching with 750 cc of water. In the cases of sodium phosphate, ammonium phosphate, and potassium phosphate, 88, 3.3, and 3.2%, respectively, of the phosphates were leached out.

Alternate wetting and drying is one of the most important factors in the fixation of phosphates in soils. When the phosphates were mixed with ¾ inch of soil, their solubility was reduced nearly one-half by each successive wetting and drying treatment. A comparison of the different phosphates shows that superphosphate is fixed fully 30 times more readily than sodium phosphate by the wetting and drying treatments.

Fertilizer salts mixed with superphosphate greatly influence the movement of the latter through soils. Sodium nitrate increased the movement of superphosphate, while potassium and ammonium sulfate slightly decreased it.

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THE EFFECT OF LIME, SUPERPHOSPHATE, AND POTASH ON REACTION OF SOIL AND GROWTH AND COMPOSITION OF ALFALFA[1]

M. C. SEWELL and W. L. LATSHAW[2]

In eastern Kansas there are soils upon which alfalfa will not grow successfully without the application of lime and superphosphate. This fact has raised the problem of the most effective combination of lime and superphosphate for maximum yield. Incidental thereto are questions relative to the result of such fertilization on the composition of hay and on soil reaction.

The soil used in these investigations was an acid Cherokee silt loam from southeastern Kansas, having a pH value of 4.97 by both the quinhydrone and hydrogen electrode methods. The experiment herewith discussed has been repeated three times over a period of 5 years. The first experiment has been previously reported (1).[3]

[1]Contribution No. 203 from the Department of Agronomy and contribution No. 157 from the Department of Chemistry, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication March 30, 1931.

[2]Associate Professor of Soils and Professor of Chemistry, respectively.

[3]Reference by number is to "Literature Cited," p. 814.

PROCEDURE

The greenhouse cultures were contained in glazed tiles, 12 inches inside diameter, and 36 inches long. The bottoms were closed, although drainage was provided, and the tiles were placed upon individual trucks in order to facilitate weighing. Each tile contained 90 to 100 kilograms of soil when moistened. Moisture content was maintained at 24%, or approximately optimum for this soil. The cultures were arranged in seven rows with six tiles in a row. The lime and superphosphate treatments were so arranged that lime applications increased linearly and superphosphate treatments perpendicularly.

The lime and superphosphate were stirred into the surface 7 inches of soil at separate times. The effects of both calcium hydroxide and calcium carbonate were tested. The rates of application of lime in terms of calcium hydroxide were 1,000, 2,000, 4,000, 8,000, and 12,000 pounds per acre. Commercial 20% superphosphate was applied at rates of 150, 300, and 450 pounds per acre. Potassium sulfate at the rate of 150 pounds per acre was applied in one row of tile receiving 300 pounds of superphosphate. For the yield determinations the alfalfa was cut when in full bloom.

EXPERIMENTAL

EXPERIMENT II, 1928–29

In the second repetition of the original experiment of 1927 fresh soil was used. The lime applications were made September 10 and samples of surface 7 inches of soil were taken October 4 for pH value determinations from tile receiving lime only. The superphosphate applications were made on October 10 and soil samples were taken to a depth of 4 inches from the phosphated soils for reaction tests. The results of soil reaction determinations are given in Table 1. It is of interest to note that on October 4 calcium carbonate had changed the soil reaction to the same extent as calcium hydroxide, both having been applied on September 10. The applications of superphosphate without lime tended to decrease slightly the acidity at the first sampling, which was soon after its application.

On October 13, inoculated alfalfa seed was planted in the tile cultures and with seedling growth plants were thinned to approximately eight plants per tile. The second soil reaction determinations were made on January 18, 1928. These results are presented in Table 2.

The January 18 soil reactions, 3 months after adding superphosphate (Table 2), show no evidence of a change in reaction due to

the application of superphosphate. Two tons of hydrated lime and 3 of the carbonate, as acre rates of application, were sufficient to bring the soil reaction to points approaching neutrality.

TABLE 1.—*Effect of lime and superphosphate on reaction in surface soil, Experiment II, Oct. 10, 1927.**

Pounds of superphosphate applied per acre	pH values† with lbs. of lime ($Ca(OH)_2$) applied per acre					
	None	1,000	2,000	4,000	8,000	12,000
None	5.0	5.4	6.1	6.4	6.9	7.3
150	5.3	5.6	5.9	6.4	6.9	7.1
300	5.4	5.5	6.0	6.3	6.7	7.1
450	5.5	5.7	6.2	6.4	6.9	7.5
30+0150 lbs. K_2SO_4	5.8	5.6	6.0	6.3	6.9	7.3
	pH values† with lbs. of lime ($CaCO_3$) applied per acre					
	None	1,470‡	2,940‡	5,880‡	11,760‡	17,640‡
None	5.0	6.0	6.2	6.6	7.0	7.2
300	5.2	5.5	6.2	6.3	6.6	7.0

*Lime applied Sept. 10; superphosphate applied Oct. 4.
†Quinhydrone electrode.
‡Calculations on basis of 92% $CaCO_3$.

TABLE 2.—*Effect of lime and superphosphate on reaction in surface soil, Experiment II, Jan. 18, 1928.**

Pounds of superphosphate applied per acre	pH values with lbs. of lime ($Ca(OH)_2$) applied per acre											
	None		1,000		2,000		4,000		8,000		12,000	
	A†	B†	A	B	A	B	A	B	A	B	A	B
None	5.2	5.1	5.7	5.5	6.5	5.9	7.7	6.5	8.0	6.8	8.2	7.0
150	4.9	4.7	5.8	5.3	6.0	5.7	7.1	6.3	7.5	6.6	7.9	7.2
300	4.9	5.0	5.4	5.3	6.2	6.0	6.6	6.1	7.1	6.4	8.0	7.6
450	5.2	5.1	6.3	5.6	6.2	5.6	6.3	5.7	8.1	6.4	8.0	6.5
300+150 lbs. K_2SO_4	4.5	4.6	5.2	5.3	6.3	5.8	7.2	6.4	8.2	6.7	7.9	7.1
	pH values with lbs. of lime ($CaCO_3$) applied per acre											
	None		1,470		2,940		5,880		11,760		17,640	
	A†	B†	A	B	A	B	A	B	A	B	A	B
None	5.3	5.1	5.6	5.6	6.1	5.8	6.9	6.2	7.3	6.7	7.9	7.0
300	5.0	4.9	5.5	5.4	5.5	5.6	7.0	6.2	7.2	6.3	7.3	6.4

*Lime applied Sept. 10; superphosphate applied Oct. 4, 1927. The pH values in this table were determined by Dr. E. L. Tague, Dept. of Chemistry.
†A, hydrogen electrode; B, quinhydrone electrode.

With acid reactions the hydrogen electrode and quinhydrone electrode readings were in agreement. Toward neutral and alkaline reactions, the readings were not in accord.

The first cutting of alfalfa was made April 20 and subsequent cuttings on June 20, July 30, October 18, and December 15, 1928. Dry weights were determined for each of the five cuttings. The total dry weights have been compiled and are given in Table 3. There are a number of irregularities in these data, yet they point to the combination of lime and superphosphate that produces the greatest yield of alfalfa. With calcium hydroxide, a 2-ton per acre rate with 450 pounds of superphosphate gave the maximum yield. There was only the one rate, i.e., 300 pounds per acre, of applying superphosphate in combination with calcium carbonate, and the maximum yields were obtained with the 2- and 6-ton equivalents of calcium hydroxide. It will be recalled that the 2-ton rate of liming caused a soil reaction well above a pH value of 6.0 and approaching neutral in some cases.

TABLE 3.—*Total dry weights of alfalfa, five cuttings, 1928.*

Pounds of superphosphate applied per acre	Grams dry weight with lbs. of lime ($Ca(OH)_2$) applied per acre					
	None	1,000	2,000	4,000	8,000	12,000
None	41	122	122	158	178	169
150	68	136	161	171	156	170
300	88	126	137	143	181	164
450	108	126	152	219	167	214
300+150 lbs. K_2SO_4	114	165	164	195	201	203
	Grams dry weight with lbs. of lime ($CaCO_3$) applied per acre					
	None	1,470	2,940	5,880	11,760	17,640
None	139.5*	135	103	137	146	171
300	147	142	173	190	160	221

*Always out of line; unaccountable growth in this tile.

After the fifth cutting of alfalfa, the tiles were emptied of soil and samples were taken from the top, middle, and bottom of the soil column. Soil reaction was determined for these three zones and the results are presented in Table 4.

The data in Table 4 show that if allowance is made for some slight variation in the pH value determinations superphosphate had no effect upon the soil reaction. A 2-ton per acre application of calcium hydroxide and a 3-ton per acre rate of carbonate lime resulted in a soil reaction approaching neutral in the surface soil.

The pH values for the middle and bottom of the soil columns (Table 4) show that the lime did not penetrate deeply enough into the soil to effect any change in the reaction of the middle and lower layers of the soil column.

TABLE 4.—*Soil reaction in top, middle, and bottom of soil columns after completion of Experiment II, spring of 1929.**

Pounds of superphosphate applied per acre	pH values† with lbs. of lime ($Ca(OH)_2$) applied per acre																	
	None			1,000			2,000			4,000			8,000			12,000		
	A‡	B‡	C‡	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
None	4.7	4.7	5.4	5.3	4.7	4.7	6.1	4.8	5.6	6.6	4.8	5.2	7.8	4.7	4.7	7.7	4.7	5.0
150	5.0	5.0	5.0	5.4	4.7	5.0	6.4	4.7	4.8	7.2	4.7	4.3	7.7	4.7	5.1	7.9	4.7	4.9
300	5.2	4.6	5.7	5.5	4.5	4.7	5.7	4.7	4.8	7.1	4.7	5.1	7.3	4.6	4.7	7.7	4.7	5.0
450	4.9	4.6	4.9	5.2	4.7	5.0	5.7	5.0	4.8	7.1	4.6	4.5	7.5	4.7	4.9	7.6	4.7	4.7
300+150 lbs. K_2SO_4	5.0	4.6	5.4	5.3	4.6	4.7	6.0	4.6	4.9	6.7	4.6	4.4	7.5	4.5	4.4	7.9	4.5	4.4
	pH values† with lbs. of lime ($CaCO_3$) applied per acre																	
	None			1,470			2,940			5,880			11,760			17,640		
	A‡	B‡	C‡	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
None	5.1	4.6	4.7	5.2	4.7	5.2	6.0	4.5	4.6	7.0	4.7	4.8	7.3	4.6	4.7	7.6	4.7	4.7

*The data in Table 4 were supplied by Dr. H. H. King and Dr. A. T. Perkins, Dept. of Chemistry.
†pH values by quinhydrone electrode, 5 grams to 12½ cc of water.
‡A, top of soil column; B, middle of soil column; C, bottom of soil column.

The first and second cuttings of alfalfa were analyzed to determine the effect of the lime, superphosphate, and potassium sulfate treatments on the nitrogen and mineral composition of alfalfa. The results of these analyses are compiled in Tables 5 and 6. The mineral analyses include the amounts of phosphorus, calcium, and potassium.

The data in Table 5 show very little change in the nitrogen content of alfalfa hay resulting from the various hydrated lime and superphosphate treatments. Where the calcium carbonate was applied there is a decrease in the percentage of nitrogen in both cuttings. However, since the visible growth and dry weights of alfalfa in the carbonate check tile culture were always out of line with the calcium hydroxide check group, no significance can be attached to this point. If the calcium carbonate were responsible for any decrease, the effect should be magnified with increasing applications, but this has not occurred.

Regarding phosphorus, there is no consistent indication that superphosphate treatments without lime increased the percentage of phosphorus in the dry matter produced. With lime, however, the application of superphosphate increased the amount of phosphorus in the plant.

Comparing the first cutting with the second cutting, the nitrogen has not varied, but in the case of phosphorus the data as a whole show a higher percentage of phosphorus in the second cutting than in the first. The first cutting was not made at as mature a stage of growth as the second cutting which may have influenced the content of phosphorus. Another explanation is the probable effect of calcium on the solubility of phosphorus. Since the growth made by the first cutting of alfalfa occurred soon after the applications of lime and phosphate, it is possible that unfixed calcium in the soil solution interfered with the absorption of phosphorus.

In Table 6 the data on calcium and potassium show that with an increase in the rate of liming there has been a decrease in the percentage of potassium in the dry matter. This depression in the amount of potassium absorption by the plant is somewhat less where the heavier superphosphate treatment accompanied the applications of lime. The percentage of calcium increased in proportion to the amount of lime applied.

SUMMARY OF EXPERIMENT II

Calcium carbonate changed the soil reaction to the same degree as an equivalent amount of calcium hydroxide, according to tests of samples taken within 30 days after the two forms of lime were applied.

TABLE 5.—*Nitrogen and phosphorus content of the first and second cuttings of alfalfa, Experiment II, 1928.*

Pounds of superphosphate applied per acre	Percentage of dry weight with lbs. of lime ($Ca(OH)_2$) applied per acre											
	None		1,000		2,000		4,000		8,000		12,000	
	N	P	N	P	N	P	N	P	N	P	N	P
None	3.39*	0.242	3.27	0.243	2.91	0.219	3.19	0.247	3.14	0.225	3.42	0.253
	3.24	0.234	3.09	0.221	3.14	0.228	2.99	0.240	3.22	0.249	3.15	0.271
150	3.39	0.231	3.42	0.219	3.15	0.218	3.23	0.223	3.27	0.230	3.29	0.236
	3.36	0.249	3.16	0.226	3.02	0.246	3.44	0.272	3.35	0.304	3.34	0.309
300	3.34	0.236	3.30	0.212	3.26	0.229	3.46	0.273	3.34	0.270	3.46	0.259
	3.32	0.267	3.31	0.230	3.37	0.259	3.22	0.311	3.41	0.335	3.33	0.315
450	3.16	0.240	3.34	0.231	3.11	0.206	2.91	0.218	3.08	0.243	3.22	0.234
	3.36	0.262	3.50	0.269	3.31	0.256	2.99	0.252	3.17	0.310	3.14	0.281
300+150 lbs. K_2SO_4	3.32	0.206	3.13	0.198	3.18	0.198	3.25	0.207	3.15	0.219	3.25	0.214
	3.06	0.225	3.13	0.241	3.05	0.243	3.30	0.256	3.11	0.312	3.07	0.289
	Percentage of dry weight with lbs. of lime ($CaCO_3$) applied per acre											
	None		1,470		2,940		5,880		11,760		17,640	
	N	P	N	P	N	P	N	P	N	P	N	P
None	3.80	0.206	3.02	0.184	3.19	0.195	3.13	0.199	3.04	0.214	3.15	0.208
	3.46	0.250	3.21	0.225	3.31	0.236	3.03	0.250	2.93	0.277	3.06	0.252
300	3.26	0.197	3.37	0.218	3.36	0.233	3.41	0.223	3.20	0.226	3.18	0.207
	3.13	0.200	3.10	0.227	3.22	0.263	3.54	0.270	3.35	0.273	3.12	0.253

*First figure for first cutting; second for second cutting.

TABLE 6.—*Calcium and potassium content of the first and second cutting of alfalfa, Experiment II, 1928.*

Pounds of superphosphate applied per acre	Percentage of dry weight with lbs. of lime ($Ca(OH)_2$) applied per acre											
	None		1,000		2,000		4,000		8,000		12,000	
	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K
None	2.09*	2.03	2.12	2.01	2.32	1.75	2.65	1.39	2.92	1.28	2.80	1.28
	1.47	2.26	1.44	2.28	1.72	1.78	1.47	1.66	1.92	1.90	1.80	1.41
150	2.38	1.95	2.64	1.77	2.52	1.55	3.00	1.45	3.04	1.92	2.74	1.39
	1.49	2.09	1.61	1.94	1.36	1.99	1.77	2.03	2.07	1.59	2.04	1.61
300	2.33	2.01	2.48	1.69	2.61	1.71	2.99	1.65	3.05	1.48	2.71	1.62
	1.80	1.81	1.42	1.97	1.46	1.75	1.83	1.54	1.97	1.86	2.28	1.98
450	2.35	1.99	2.67	1.87	2.89	1.78	2.67	1.55	2.77	1.79	2.74	1.45
	1.42	2.43	1.33	2.04	1.40	2.14	1.60	1.87	2.03	1.65	1.77	1.69
300+150 lbs. K_2SO_4	2.11	2.41	2.67	1.55	2.67	2.01	2.71	2.01	2.71	1.82	2.68	1.87
	1.29	2.66	1.36	1.78	1.51	2.25	1.81	2.04	1.72	2.19	1.77	2.14
	Percentage of dry weight with lbs. of lime ($CaCO_3$) applied per acre											
	None		1,470		2,940		5,880		11,760		17,640	
	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K
None	2.34	2.45	2.37	2.09	2.60	1.79	2.83	1.66	2.76	1.50	2.63	1.60
	1.51	2.32	1.48	2.24	1.59	2.30	1.78	1.88	2.01	1.51	1.74	1.82
300	2.37	1.70	2.57	1.78	2.61	1.90	3.08	1.37	2.64	1.64	2.78	1.45
	1.42	2.20	1.51	1.99	1.58	2.16	1.84	2.01	1.71	2.01	1.69	1.70

*First figure for first cutting; second figure for second cutting.

The application of superphosphate tended to decrease soil acidity soon after its application, but 4 months later there was no appreciable difference in soil reactions due to applications of superphosphate.

Maximum yields were obtained with the 450-pound per acre rate of superphosphate combined with a 2-ton rate of hydrated lime. With calcium carbonate, only one rate of phosphating was used, namely, 300 pounds per acre. This rate, together with lime at a rate equivalent to 2 tons of hydrated lime, produced the most economical yield for the carbonate group, although the maximum was produced by the heaviest application of calcium carbonate.

A 2-ton rate of applying hydrated lime, or its equivalent as carbonate, brought about a soil reaction approaching neutral or well above a pH value of 6.5.

The effect of lime in changing soil reaction did not extend below the surface soil. Evidently lime, either as hydrated or carbonate, did not leach to lower levels sufficiently to change the soil reaction during the time required to grow the five cuttings of alfalfa.

Chemical analyses of the alfalfa show that the nitrogen content has not, on the whole, varied with the various lime and superphosphate treatments. Superphosphate treatments alone have not increased the percentage of phosphorus in the dry matter produced, but applications of both superphosphate and lime have resulted in an increased amount of phosphorus in the alfalfa. The potassium content of the plant decreased as the rate of liming increased.

EXPERIMENT III, 1929–30

For the third repetition of the experiment fresh soil was shipped from a location adjoining the Columbus, Kansas, experimental field, this field being the source of previous soil used. The tiles were filled about August 10, 1929, after the soil had been dried and screened.

The lime treatments, all calcium carbonate, were worked into the surface soil on August 10. A new lime treatment was included in Experiment III in order to have a series of tile in which the soil contained an excess of calcium. In one row of tile in this series, calcium carbonate was mixed throughout the column of soil in amounts equal to 3% of the dry weight of soil. The superphosphate and potassium sulfate applications were mixed into the surface soil on September 6, a month later.

In addition to the change in the lime treatments, additional potassium sulfate applications were also included in Experiment III. These treatments will be indicated in the tables in which the data are presented.

TABLE 7.—*Effect of applications of lime, superphosphate, and potassium sulfate on soil reaction, Experiment III.**

Pounds of superphosphate applied per acre	pH values† with various amounts of lime ($CaCO_3$) per acre															
	None			1 ton			2 tons			3 tons			4 tons		3% dry weight	
	A‡	B‡	C‡	A	B	C	A	B	C	A	B	C	A	C	A	C
None	4.9	5.2	5.2	5.4	5.9	6.5	6.8	6.8	6.9	6.9	6.8	7.4	6.6	7.7	7.8	8.0
150	4.5	4.9	5.2	5.7	6.3	6.5	6.5	6.6	6.9	6.9	6.9	7.6	6.8	7.7	7.8	8.0
300	4.4	4.4	5.4	5.7	6.1	5.4	7.0	7.0	6.1	7.1	7.0	6.3	7.4	7.0	7.6	7.9
450	4.9	5.0	4.0	5.7	6.1	5.6	6.7	6.7	5.8	7.1	6.8	6.3	7.2	6.2	7.9	7.8
300+150 lbs. K_2SO_4	4.7	4.8	4.9	5.5	6.0	5.6	6.7	6.5	5.9	7.2	6.9	6.5	7.4	7.4	7.7	7.9
300+300 lbs. K_2SO_4	4.6	4.7	5.3	5.6	5.8	6.1	6.5	6.8	7.1	7.2	7.1	6.9	7.3	6.7	7.6	7.8
300+450 lbs. K_2SO_4	5.0	4.8	5.2	5.4	6.0	6.0	6.4	6.5	6.7	6.9	6.9	6.6	7.2	7.1	7.6	7.8

*Lime applied Aug. 10, 1929; superphosphate and potassium sulfate, Sept. 6, 1929.
†Quinhydrone electrode.
‡A, November 1929; B, December, 1929; C, March, 1930.

The applications of lime, superphosphate, and potassium sulfate were based on surface area of soil. The lime applied varied from 20 to 80 grams per tile for the 1- to 4-ton rates. For the 3% by weight application, 2,270 grams of calcium carbonate were mixed throughout the soil column. The quantities of superphosphate and potassium sulfate varied from 1.54 to 4.62 grams per cylinder.

The soil was maintained at approximately 25% moisture, the tile cultures being weighed from time to time in order to check the moisture content. With 25% moisture the weight of soil was about 100 kilograms.

Inoculated alfalfa seed was planted in the tiles directly following the superphosphate and potassium sulfate applications made on September 6.

The reaction of the soil was determined from surface samples (4 inches) in November and December 1929 and in March 1930. The pH value representing the reactions are compiled in Table 7.

The reaction data show quite close agreement between the readings of November and December 1929. The March 1930 pH values are higher for the 3- and 4-ton rates of lime alone and lime plus the light applications of superphosphate.

The 2-ton rate of liming brought about a soil reaction well above a pH value of 6.5 in most cases and a 3-ton rate a reaction near neutral, with few exceptions.

During the course of Experiment III, four cuttings of alfalfa were made from the tile cultures. The dates of the cuttings were March 15, May 2, June 13, and July 18. The total dry weights have been summarized and presented in Table 8.

TABLE 8.—*Total dry weights of four cuttings of alfalfa, Experiment III, 1930.*

Pounds of superphosphate applied per acre	Grams of dry weight with various amounts of lime ($CaCO_3$) per acre					
	None	1 ton	2 tons	3 tons	4 tons	3% dry weight
None	102.7	108.3	123.9	94.4	130.5	175.1
150	101.4	117.2	131.9	140.0	125.6	180.6
300	85.5	119.9	145.6	134.6	128.1	192.4
450	116.1	120.6	101.4	142.1	123.1	200.4
300+150 lbs. K_2SO_4	87.1	120.0	116.2	131.8	115.3	196.8
300+300 lbs. K_2SO_4	66.0	118.1	109.0	139.5	133.0	188.2
300+450 lbs. K_2SO_4	100.3	134.0	117.3	144.6	120.8	189.7

Total dry weight of each cutting:
First.. 1127.0 grams
Second.. 1817.4 grams
Third.. 1558.2 grams
Fourth... 967.4 grams

The yield or dry weight data presented in Table 8 show that the high lime (3% of dry weight of soil) treatments have produced the greatest yields, both with lime alone and where lime was applied with superphosphate. The highest yield was produced with the 450-pound per acre rate of superphosphate and 3% calcium carbonate. The highest yield with the 150-pound per acre rate of superphosphate was with 3 tons of lime. With 300 pounds per acre of superphosphate, the highest yield was with the 2-ton rate of liming. According to previous experiments, 450 pounds of superphosphate and 2 tons of lime should equal or exceed the lighter applications of superphosphate. Notes taken when the tile was emptied indicated a wet condition of this soil, which may account for the low yield.

The potassium sulfate treatments do not indicate any response to potassium applied in addition to the phosphate.

Root growth was found to be much less in the unlimed series than in the limed series.

The second cutting of alfalfa on May 2 was saved for chemical analysis to determine the percentage composition of nitrogen, phosphorus, calcium, and potassium. These results are given in Tables 9 and 10.

The nitrogen and phosphorus data of Table 9 do not show any consistent variation in the nitrogen content of the alfalfa attributable to the soil treatments. Without lime, the phosphorus content of the plants did not increase with the increasing rates of superphosphate. However, with applications of lime and superphosphate, the percentage of phosphorus in the dry matter increased with increases in the rate of superphosphate application.

The potassium analysis data of Table 10 show again the marked effect of lime alone in decreasing the percentage of potassium. The decrease is in proportion to the amount of lime applied to the soil. Where potassium sulfate was added, the potassium in the dry matter increased even with the heavier rates of liming. Again the calcium content increased with the increased rate of liming. This increase is most noticeable in the cultures with 3% $CaCO_3$.

The ash content of the second cutting of alfalfa produced in Experiment III was determined and the data are incorporated in Table 11. These results are of interest from the viewpoint that feeders have been led to believe that alfalfa grown on highly mineralized soil contains an abundance of mineral. In the case of the analyses shown, the total mineral content has not been changed with increasing rates of applying lime, superphosphate, and potassium sulfate in comparison with the no-treatment culture. However, it

TABLE 9.—*Nitrogen and phosphorus content of the second cutting of alfalfa, Experiment III, 1930.*

Pounds of superphosphate applied per acre	Percentage of dry weight with various amounts of lime ($CaCO_3$) per acre											
	None		1 ton		2 tons		3 tons		4 tons		3% by weight	
	N	P	N	P	N	P	N	P	N	P	N	P
None	4.12	0.321	3.85	0.262	3.84	0.270	3.81	0.252	3.91	0.241	3.90	0.300
150	3.89	0.292	3.83	0.283	3.93	0.306	3.95	0.308	3.77	0.290	3.91	0.332
300	3.58	0.275	3.73	0.308	3.91	0.323	3.80	0.314	3.78	0.336	3.87	0.351
450	3.91	0.283	3.75	0.328	3.96	0.360	3.89	0.360	3.91	0.381	4.08	0.401
300+150 lbs. K_2SO_4	4.00	0.296	3.74	0.299	3.89	0.326	3.79	0.337	3.73	0.333	3.90	0.357
300+300 lbs. K_2SO_4	3.26	0.254	3.61	0.272	3.51	0.300	3.71	0.338	3.47	0.328	3.81	0.354
300+450 lbs. K_2SO_4	3.89	0.289	3.63	0.300	3.82	0.318	3.77	0.302	3.72	0.325	3.68	0.369

TABLE 10.—*Calcium and potassium content of the second cutting of alfalfa, Experiment III, 1930.*

Pounds of superphosphate applied per acre	Percentage of dry weight with various amounts of lime ($CaCO_3$) per acre											
	None		1 ton		2 tons		3 tons		4 tons		3% by weight	
	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K	Ca	K
None	1.49	2.63	1.51	2.46	1.46	2.32	1.64	2.20	1.59	2.53	1.89	1.82
150	1.55	2.26	1.52	2.29	1.57	2.40	1.54	2.08	1.47	2.11	1.76	1.94
300	1.46	2.45	1.55	2.19	1.46	2.23	1.56	2.30	1.78	2.18	1.80	1.74
450	1.44	2.41	1.41	2.11	1.52	2.17	1.51	2.12	1.55	2.06	1.80	1.93
300+150 lbs. K_2SO_4	1.48	2.40	1.43	2.24	1.35	2.23	1.40	2.24	1.50	2.24	1.75	1.99
300+300 lbs. K_2SO_4	1.49	2.23	1.31	2.58	1.48	2.68	1.55	2.75	1.34	2.53	1.79	1.93
300+450 lbs. K_2SO_4	1.40	2.32	1.31	2.52	1.46	2.61	1.39	2.76	1.47	3.19	1.67	2.15

should be noted that the heaviest application of potassium sulfate in connection with superphosphate and the 2- and 4-ton rates of liming did step up the ash content of alfalfa in comparison with the lighter applications of potassium. We have previously discussed the fact that liming and superphosphate plus lime increased the percentage of calcium and phosphorus in the alfalfa.

TABLE 11.—*Ash content of alfalfa, second cutting, Experiment III, 1930.*

Pounds of superphosphate applied per acre	Percentage ash, dry weight, with various amounts of lime ($CaCO_3$) per acre					
	None	1 ton	2 tons	3 tons	4 tons	3% dry weight
None	10.58	9.54	8.91	9.14	10.58	10.41
150	9.75	9.10	9.35	9.14	9.35	10.14
300	9.48	8.83	8.87	9.11	9.83	9.22
450	9.13	8.67	9.03	9.17	8.89	9.45
300+150 lbs. K_2SO_4	9.55	8.87	8.74	9.18	9.23	9.49
300+300 lbs. K_2SO_4	8.87	9.27	9.24	9.77	8.97	9.30
300+450 lbs. K_2SO_4	9.90	9.62	10.39	9.87	10.97	9.37

During the course of Experiment III, careful determinations were made of the moisture in the four cuttings of alfalfa. This moisture data, averaged for the four cuttings, is presented in Table 12. It is significant that the moisture content of the hay is, with one exception, lower in the alfalfa grown on the soil high in calcium (3% $CaCO_3$). The exception is where the 450-pound per acre rate of superphosphate was applied.

TABLE 12.—*Average moisture content of four cuttings of alfalfa, Experiment III, 1930.*

Pounds of superphosphate applied per acre	Percentage of moisture, dry weight basis, with various amounts of lime ($CaCO_3$) per acre					
	None	1 ton	2 tons	3 tons	4 tons	3% dry weight
None	82.0	81.2	79.9	81.1	80.9	77.7
150	80.9	80.2	79.8	79.7	79.8	77.7
300	80.3	79.7	80.1	79.7	80.0	77.6
450	80.1	79.9	80.8	79.4	80.8	80.0
300+150 lbs. K_2SO_4	80.3	79.2	81.0	80.3	80.7	79.1
300+300 lbs. K_2SO_4	85.5	80.1	80.2	80.9	80.1	79.1
300+450 lbs. K_2SO_4	79.3	79.8	80.3	79.7	80.3	77.1

GENERAL SUMMARY

In Experiment I, results of which have been published, notation was made that applications of superphosphate tended to modify the specific reaction of the soil under investigation, reducing the degree

of acidity. From the results of Experiments II and III, it is apparent that this reduction in acidity lasts for only a short period following the application of superphosphate. Subsequent determinations made several months later show that superphosphated soils have about the same reaction as the untreated soil.

The alfalfa yields in Experiments II and III were in agreement with Experiment I in that the application of superphosphate in addition to lime seemed to produce yields equal to those secured from heavier rates of applying lime alone.

That the application of lime and superphosphate changes the rate of absorption of some of the primary nutritive elements is another conclusion of Experiment I with which the results of Experiments II and III agree.

The fact that applications of superphosphate alone did not increase the percentage of phosphorus in the dry matter produced but that superphosphate with lime did increase it is in line with certain literature on this subject.

Thomas (2), after reviewing experimental work dealing with factors affecting solubility of phosphates, states, "The tenacity with which these absorbed ions will be held will vary with the potential differences developed and therefore upon other cations and anions present in the absorption complex. The concentration of the PO_4 in the colloidal surfaces will be determined by the Gibbs-Donnan equilibrium law." In support of these facts Thomas refers to the investigations of Wolkoff (3), which led to the conclusion that PO_4 ions of superphosphate may be so strongly absorbed by some soils that acids may dissolve no more phosphorus from such treated soils than from soils supplied with rock phosphate; of Gile and Smith (4), from whose work it may be stated that it frequently happens that as much as 20% of the applied phosphorus is not recovered in the crop; and of Wheeler and Adams (5), who concluded from their experiments on peat and muck soils that "saturation of the soil colloids was necessary before additions of phosphates became effective."

Where no superphosphate was applied, the percentage of phosphorus in the plants decreased with applications of lime, except where the lime, 3% by weight, was mixed throughout the soil column. With a soil deficient in calcium and phosphorus, the depression in phosphorus absorption with increasing calcium may be explained according to the deductions of Liebig, quoted by Thomas (6), "that nutrient elements are absorbed in certain definite proportions in such a manner that a limit having been reached by one, the absorption of the others is retarded."

The potassium composition of the alfalfa was very markedly affected by applications of lime, decreasing in proportion to the rate of liming. Since more calcium was absorbed in proportion to the rates of applying lime, it is possible that a greater amount of calcium absorbed by the cell structure may have affected the permeability of cell walls to potassium ions.

A fourth statement in the summary of Experiment I, was that evidence indicated that the response of a soil to a given nutritive element cannot be determined from one rate of application of the fertilizer carrier of the element under consideration. Subsequent data of Experiments II and III substantiate this statement.

In Experiment III, the influence of an excess of lime on the growth of alfalfa is striking. The soil with 3% calcium carbonate produced in four cuttings 175.1 grams dry weight of alfalfa in comparison with 130.5 grams on soil receiving lime at the rate of 4 tons per acre. This is a difference of 34%. Approximately this difference exists in the dry weights of the alfalfa produced in the high-calcium soil compared with those receiving surface applications of calcium regardless of the amount of other fertilizer treatments.

A logical conclusion to be drawn from the foregoing is that, other conditions being uniform, one could expect greater success in raising alfalfa on land naturally supplied with lime in comparison with lands where lime must be added artificially.

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SURFACE RUN-OFF AND EROSION IN RELATION TO SOIL AND PLANT COVER ON HIGH GRAZING LANDS OF CENTRAL UTAH[1]

George Stewart and C. L. Forsling[2]

Erosion seems to be a leak that is almost continent-wide (2)[3]. It has deserved the important attention given to it for many years in the southern and southeastern parts of the United States. More recently, its serious aspects in the corn belt and lake states has been recognized (1, 3). Recently, also, the damaging consequences of erosion in the western states (4, 5) on forest and range lands, as well as on cultivated areas, has thrust itself upon our attention. Our limited knowledge has in part been responsible for the unhappy results of little-managed grazing, one of the several consequences of which too frequently is the loss of the more productive surface soil. Erosion in the geologic sense is always going on, but it is only of late that it has come to exceed the processes of weathering and the decay of plant parts which make for soil accumulation and soil improvement. This turning of the balance from a slight accretion to a fairly rapid removal of soil is for the present purpose summed up in the word "erosion."

Since 1915, the research branch of the U. S. Forest Service has maintained at the Great Basin Branch Experiment Station, on the Ephraim Canyon watershed of the Manti Forest in central Utah, a detailed study of the relation of vegetative cover and grazing to surface run-off and erosion. This is in a locality 10,000 feet above sea level, where the annual precipitation, more than two-thirds of which is winter snow, is about 30 inches. Two somewhat equal drainage areas with distinctly different plant cover were placed under control and the water led through covered settling tanks equipped for measuring the water and the eroded material. Rain gauges on the two areas measure the rainfall from each summer storm, and in later years tipping-bucket gauge records have been obtained to determine the rate of fall as well as the amount. The two watersheds, 882 feet apart, are subject to the same climatic influences.

One area designated as "B" has had throughout a plant cover occupying 40% of the surface of the ground and the other from 1912 to 1919 had a cover of 16%. The second area, designated as "A,"

[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication March 23, 1931.

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[3]Reference by number is to "Literature Cited," p. 832.

had been heavily overgrazed and was considerably eroded when the study began and has since been further eroded. Between 1919 and 1924 area "A" was so treated that its plant cover was built up to 40% at which level it was kept until the present. There are available for comparison data for three periods, *viz.*, one of 6 years from 1915 to 1920, inclusive, when area "A" with a 16% plant cover is compared with "B" which had an old plant cover of 40%; the second period from 1921 to 1923, inclusive, during which the plant cover of "A" was built up; and the third period from 1924 to 1929, inclusive, during which area "A", with a newly acquired 40% cover, is compared with area "B" with the old 40% cover. In addition, the run-off and erosion from melted snow is compared with run-off and erosion from summer rainfall.

The soils of both areas originated from limestone and shale. The raw unweathered soil is fine-particled, very adhesive when wet, and hard when dry. Where undisturbed, as on most of the well-vegetated area, the surface soil is dark-colored and rich in organic matter to a depth of 3 to 6 inches. Beneath this is a layer of from 4 to 12 inches of friable clay fairly rich in organic matter and in plant nutrients. On much of the depleted plat these two layers had been eroded previous to 1915 to such an extent as to expose a raw inert clay low in organic matter and plant nutrients and very favorable to rapid run-off. A survey showed 65.7% of the depleted area having a surface soil favorable to rapid runoff, whereas on the well-vegetated plat only 11.5% of the area had been so denuded of its surface soil.

The grazing record for the two experimental watersheds is shown in Table 1. During the summer seasons of 1914 to 1919, inclusive, both areas were grazed with sheep during late July or the first half of August. This grazing maintained the plant covers at 16 and 40%, respectively, for the two plats, following which the vegetation on the depleted plat "A" was permitted to increase. In order to bring this about a portion was seeded to native grasses and grazing was omitted on this depleted area until 1924 at which time the vegetation was estimated to be a 40% plant cover. The qualities of the soil were still, however, far different from those on the well-vegetated area B. The new cover of 40% on A was not really comparable with the long-established cover of 40% on B, which had been grazed each season by sheep. From 1925 to 1929, inclusive, the well-vegetated area B was grazed twice, once with cattle and again with sheep. The newly improved area A was grazed once with cattle in 1925, rested in 1926, and grazed once with sheep in 1927, 1928, and 1929 late in the season after seed maturity.

TABLE 1.—*Date of grazing and class of livestock grazed on watershed A and on watershed B.*

Year	Area		Class of stock	Year	Area		Class of stock
	A	B			A	B	
1914....	Aug. 10	Aug. 11	Sheep	1922...	—	Aug. 14	Sheep
1915....	Aug. 2	Aug. 3	Sheep	1923...	—	Aug. 17	Sheep
1916....	Aug. 8	Aug. 1 and 9*	Sheep	1924...	—	Aug. 16	Sheep
1917....	Aug. 15	Aug. 16	Sheep	1925...	—	Aug. 19	Sheep
					Sept. 15	—	Cattle
1918....	Aug. 17	Aug. 18	Sheep	1926...	—	July 14–17	Cattle
					—	Aug. 13	Sheep
1919....	July 28	July 27	Sheep	1927...	—	Aug. 2–4	Cattle
					Sept. 24	—	Sheep
1920....	—	Aug. 5	Sheep	1928...	—	July 16–18	Cattle
					—	Aug. 9	Cattle
					Oct. 2	—	Sheep
1921....	—	July 31	Sheep	1929...	—	July 22	Cattle
					—	Oct. 1–2	Cattle
					Oct. 2	—	Sheep

*Grazing was not sufficiently heavy on August 1.

During the 12 years from 1912, when the plant types on A were first listed, to 1924, when the increase noted was regarded as accomplished, there was a considerable change in individual species in sub-area types, as follows:

1912	1924
Yarrow (*Achillea lanulosa*), needle grass (*Stipa lettermani*), cinquefoil (*Potentilla filipes*)	Wheatgrass (*Agropyron violaceum*), needlegrass, yarrow
Yarrow, knotweed (*Polygonum spp.*)	Sweetsage (*Artemisia incompta*), mountain-dandelion (*Agoseris pumila*), wheatgrass, many-flowered brome (*Bromus polyanthus*)
Pentstemon (*Pentstemon rydbergii*), larkspur (*Delphinium barbeyi*), sweetsage	Pentstemon, wheatgrass, sweetsage.
Wild currant (*Ribes spp.*), yarrow	Wild currant, dandelion (*Leontodon taraxacum*), wheatgrass.
Nevada bluegrass (*Poa nevadensis*), wheatgrass, needlegrass	Nevada bluegrass, wheatgrass
Larkspur, pentstemon, knotweed	Larkspur, sweetsage, mountain-dandelion
Elder (*Sambucus microbotrys*)	Elder
Alpine fir (*Abies lasiocarpa*)	Alpine fir

The poor annual weed, knotweed, was almost entirely replaced by the more desirable perennial weeds, such as yarrow, sweetsage, and mountain dandelion, while these in turn were partly replaced by wheatgrass and many-flowered bromegrass. As a whole, wheat-

grass greatly increased. There was some change in the vegetation between 1912 and 1920, but most of it came between 1920 and 1924 while the area was ungrazed.

An earlier study (6) on this same mountain range has shown that on undamaged areas with a well-preserved soil, wheatgrasses are the predominant plants, while under severe grazing the grasses are gradually replaced by shrubs and desirable perennial weeds. Under prolonged destructive grazing, coarse unpalatable perennials and annuals were the resultant plants. On practically denuded areas, such as bedgrounds used for long periods, about the only plant to persist was Douglas knotweed (*Polygonum douglasii*). The plant succession during revegetation of the range following regulation of grazing was approximately in the reverse order of the destructive process.

SUMMER PRECIPITATION

Since run-off is in part a function of the rainfall, precipitation data are presented in Table 2. This table presents the data for total summer rainfall precipitation in the first part and for "effective" precipitation in the second part. Only those storms causing run-off are classified as "effective" for their respective areas. As run-off occurred more readily on the depleted area, the number of effective storms was greater on this area.

During the first 6-year period, 1915–20 inclusive, there was an average of 25.3 storms yearly on each area, giving an average of 5.075 and 5.335 inches for the depleted and the well-vegetated areas, respectively. This amounts to 18,422 cubic feet of total rainfall on each acre of the depleted area as compared with 19,366 cubic feet on each acre of well-vegetated area. The well-vegetated area received therefore 5.1% more water on each acre than did the depleted area. During the 1921–23 period, the amounts were more nearly equal, differing only by 5.733 and 5.810 inches, or by 20,812, and 21,090 cubic feet per acre, respectively, with the well-vegetated area again receiving a slight excess of 1.3%. During the period of 1924–29, there was again a slight excess of precipitation on the area which was originally well covered. In the 25.2 storms yearly the average precipitation was 4.202 and 4.327 inches or 15,253 and 15,707 cubic feet per acre, a difference of 2.97%. These differences are all slight and probably within the natural variability of summer rainfall, but they all show slightly more rainfall on the well-vegetated area. From this standpoint alone, there should have been either a slightly greater or at least an equal amount of run-off from the well-covered area.

TABLE 2.—*Number of storms and total precipitation by summer rainfall and "effective" precipitation on area A and on area B.*

Year	No. of storms	Watershed A		Watershed B	
		Inches	Cu. ft. per acre	Inches	Cu. ft. per acre
		Summer Precipitation			
1915....	19	3.26	11,834	3.97	14,411
1916....	28	4.34	15,754	5.06	18,368
1917....	18	4.13	14,992	4.11	14,919
1918....	31	8.08	29,330	7.70	27,951
1919....	28	5.71	20,727	6.44	23,377
1920....	28	4.93	17,896	4.73	17,170
Average.	25.3	5.075	18,422	5.335	19,366
1921....	30	7.77	28,205	7.78	28,241
1922....	32	4.29	15,573	4.57	16,589
1923....	34	5.14	18,658	5.08	18,440
Average.	32.0	5.733	20,812	5.81	21,090
1924....	18	3.29	11,943	3.21	11,652
1925....	32	5.15	18,695	5.72	20,764
1926....	24	4.77	17,315	4.71	17,097
1927....	28	5.97	21,671	6.10	22,143
1928....	13	1.23	4,465	1.26	4,574
1929....	36	4.80	17,424	4.96	18,005
Average.	25.2	4.202	15,253	4.327	15,707

Year	Watershed A			Watershed B		
	No. of Storms	Inches	Cu. ft. per acre	No. of storms	Inches	Cu. ft. per acre
			Effective Precipitation			
1915....	1	0.70	2,541	1	1.43	5,191
1916....	9	1.74	6,316	3	0.92	3,339
1917....	5	2.12	7,696	1	1.09	3,957
1918....	8	5.01	18,187	6	3.26	11,834
1919....	5	2.70	9,801	3	2.08	7,551
1920....	5	2.33	8,458	2	1.25	4,538
Average	5.5	2.433	8,833	2.7	1.672	6,067
1921....	14	5.20	18,876	12	4.82	17,497
1922....	6	2.00	7,259	3	1.18	4,283
1923....	3	1.52	5,517	2	1.10	3,993
Average	7.7	2.907	10,551	5.7	2.367	8,591
1924....	1	0.80	2,904	1	0.88	3,194
1925....	4	1.07	3,884	3	0.59	2,142
1926....	5	2.40	8,712	2	0.79	2,868
1927....	7	2.72	9,874	3	1.48	5,372
1928*...	–	——	——	–	——	——
1929....	6	1.95	7,079	1	0.60	2,178
Average	3.8	1.490	5,409	1.7	0.723	2,626

*No effective storms.

The second part of the table shows no such result. Twice as many storms caused run-off on the depleted area, most of the smaller ones not being "effective" on the well-vegetated area. The storms causing run-off averaged 2.433 inches or 8,833 cubic feet of water per acre on the depleted area as compared with 2.7 storms, 1.672 inches, and 6,067 cubic feet of water to the acre on the other area. In other words, while 5.1% more water fell on the area with a good plant cover, the amount which fell during storms causing run-off was 31.3% less during the early period. In the 1921–23 period, there was 1.3% more total summer rainfall but 18.6% less in the storms causing run-off. During 1924–29, after the denuded area was restored to 40% cover, precipitation in the storms having run-off was only half as great on the area originally well-vegetated, even though the total precipitation was 2.97% greater.

The relative number of storms causing run-off from the newly vegetated as compared to the older vegetated area was greater during the period after the vegetation had increased to 40% than it was in either of the previous periods. The reason for this is not obvious as the opposite might have been expected. However, the number of storms causing run-off on each area was probably influenced by the character of the rainfall and other conditions as much as by plant cover alone and, as will be shown, the amounts of run-off and erosion both decreased regularly with the improvement in plant cover.

The difference in run-off between the two areas is even greater than the difference in rainfall of effective storms, as is shown by referring to Table 3 in which is given on an acre basis for the two areas the total number of cubic feet of run-off, the percentage of the effective rainfall which ran off, the number of cubic feet of sediment carried, and the cubic feet of sediment in each 1,000 cubic feet of water run-off. In addition, the A/B ratios are also given for volume of run-off, for percentage of storms which caused run-off, and for volume of sediment removed.

During the first 6-year period, while the poorly-vegetated area had a 16% cover, the run-off from summer rainfall averaged about 913 cubic feet of water and 134 cubic feet of sediment annually on the depleted area as compared with 153 cubic feet of water and 25 cubic feet of sediment to the acre annually on the area which had a plant cover of 40%. Of the precipitation which fell during storms that caused run-off, 10.33 and 2.52%, respectively, ran off the depleted and the well-vegetated areas. The A/B ratio shows that 4.1 times as high a percentage of the effective precipitation ran off the de-

TABLE 3.—*Summary of run-off and erosion due to summer rainfall in three different periods on area A and area B.*

Year	Values per acre for watershed A				Values per acre for watershed B				A/B ratios		
	Surface run-off*		Sediment in cu. ft.	Sediment in 1,000 cu. ft.	Surface run-off*		Sediment in cu. ft.	Sediment in 1,000 cu. ft.	Run-off volume	%	Sediment in cu. ft.
	Cu. ft.	%			Cu. ft.	%					
1915	245.2	9.65	63.8	260.2	26.6	0.51	10.6	398.5	9.22	18.92	6.02
1916	128.6	2.04	28.9	224.7	74.4	2.23	11.7	157.3	1.73	0.91	2.47
1917	505.5	6.57	109.4	216.4	56.8	1.44	6.4	112.7	8.90	4.56	17.09
1918	1,484.7	8.16	243.3	163.9	14.6	0.12	2.7	184.9	101.69	68.00	90.11
1919	2,405.3	24.54	241.3	100.3	629.3	8.33	80.4	127.8	3.82	2.95	3.00
1920	706.4	8.35	116.2	164.5	117.1	2.58	36.2	309.1	6.03	3.24	3.21
Average	912.6	10.33	133.82	146.6†	153.1	2.52	24.67	161.1†	5.96	4.10	5.42
1921	1,828.1	9.68	186.7	102.1	505.4	2.89	65.3	129.2	3.62	3.35	2.86
1922	290.9	4.01	50.6	173.9	68.2	1.59	21.5	315.2	4.27	2.52	2.35
1923	646.5	11.72	77.8	120.3	208.2	5.21	25.1	120.6	3.11	2.25	3.10
Average	921.8	8.74	105.03	113.9†	260.6	3.03	37.30	143.1†	3.54	2.88	2.82
1924	2.4	0.08	Trace	Trace	2.7	0.08	Trace	Trace	0.89	1.00	Trace
1925	23.1	0.59	1.1	47.6	19.4	0.91	Trace	Trace	1.19	0.65	Trace
1926	62.4	0.72	11.7	187.5	37.9	1.32	2.4	63.3	1.65	0.55	4.88
1927	1,544.8	15.65	85.7	55.5	758.5	14.12	43.5	57.4	2.04	1.11	1.97
1929	149.9	2.12	16.4	109.4	6.2	0.28	0.5	80.6	24.18	7.57	32.80
Average	297.1	5.49	19.15	64.5†	137.4	5.23	7.73	56.3†	2.16	1.05	2.48

*Percentages are based on precipitation during storms from which surface run-off occurred
†Weighted means; others straight averages.

pleted area, making 5.96 times as much run-off water which carried with it 5.42 times as much sediment. For the amount of water that did run off, however, there was slightly more sediment from the well-vegetated area. This is shown by the fact that 161.1 cubic feet of sediment came from this area for each 1,000 cubic feet of water as compared with 146.6 cubic feet for each 1,000 cubic feet of water from the depleted area. This is probably due to the fact the amount of run-off from the well-covered area was much smaller for each effective storm. The first part of the run-off brings with it the loose soil, the percentage sediment usually being higher in the early part of the run-off. During protracted run-off the percentage of sediment usually decreased after a time.

Between 1920 and 1924 the vegetation on the depleted area increased from 16 to 40%. The three years 1921, 1922, and 1923 are therefore studied by themselves. It will be recalled (Table 1) that only the better-covered area was grazed during this period. These seasons yielded run-off and erosion data which are intermediate between the period of 1915–20 and the 6-year period, 1924–29, when both areas had 40% covers.

During the 5-year period of 1925–29, the formerly depleted plat had a cover equal in density to the other plat. It was, however, a newly established cover and had still a soil with most of the qualities it formerly possessed as an eroded plat. The surface run-off per acre from the older vegetated area was 137 cubic feet of water, almost identical with the run-off for the period of 1915–20, but the sediment was only one-third as great. The newly vegetated area showed the effect of the increase in cover by a reduction in run-off from 913 to 297 cubic feet per acre. This is a decrease when properly equated against the difference in run-off during the two periods on the older vegetated area of 63.8% due to increasing the vegetation from 16 to 40% of a complete plant cover. The run-off was still 2.16 times and the sediment 2.48 times as great from the newly vegetated plat. Part of this difference is due to the lack of organic matter in the surface soil. Unfortunately it is not possible to give these three factors of soil, rainfall, and plant cover their exact weighting as all of them influence run-off and erosion.

The sediment carried off each acre by summer rainfall run-off of the newly vegetated area averaged approximately 19 cubic feet annually, which is only one-seventh as much as the 134 cubic feet which occurred in 1915–20. When properly equated against the reduction in erosion from the older vegetated plat, there was a decrease of 54.2% due to increasing the vegetation from a 16 to a 40% cover.

In Table 4 the data of storms for the entire period are summarized and classified as to the amount of run-off water that resulted in classes ranging from 10 cubic feet and less up to those storms producing more than 400 cubic feet of run-off water to the acre. On the originally depleted area, 57 storms are so classified of which 20, or 35%, produced more than 100 cubic feet of run-off water. In comparison, on the well-vegetated area there were 36 storms causing run-off but only 6, or 17%, that caused more than 100 cubic feet. It is especially noteworthy that seven storms each produced more than 400 cubic feet of run-off from the depleted area as compared with one such storm from the other area. The average was 884 cubic feet per acre for these heavy storms from the depleted area as compared with 481 cubic feet from the area with a good plant cover.

TABLE 4.—*Summer rainfall storms from 1915 to 1929 grouped in run-off classes from watersheds A and B.*

Run-off class, cu. ft.	Watershed A				Watershed B			
	No. of storms	Run-off in cu. ft.*	Sediment eroded in cu. ft.	Sediment per 1000 cu. ft. of run-off, cu. ft.	No. of storms	Run-off in cu ft.*	Sediment eroded in cu. ft.	Sediment per 1000 cu. ft. of run-off, cu. ft.
0.1– 10.0	8	4.59	0.75	163.4	11	3.59	0.56	156.0
10.1– 50.0	19	28.12	4.39	156.1	12	30.40	5.85	192.4
50.1–100.0	10	72.71	17.12	235.5	5	63.00	11.62	184.4
100.1–200.0	7	121.43	16.87	138.9	1	193.90	23.10	119.1
200.1–300.0	4	242.60	38.18	157.4	3	244.47	19.83	81.1
300.1–400.0	2	343.40	48.05	139.9	1	368.90	59.20	160.5
400.1–up	7	884.27	86.49	97.8	1	481.20	30.00	62.3

*Cu. ft. of run-off can be translated into inches of run-off by multiplying the number of cu. ft. by 0.0002755.

On the well-covered area, of the 36 storms causing run-off, 23, or 64%, produced not to exceed 50 cubic feet of run-off water from each acre with an average of 30.4 cubic feet; whereas on the depleted area of the 57 storms causing run-off, 27, or 47%, produced not to exceed 50 cubic feet from each acre with an average of 28.1 cubic feet. There was, therefore, a decided tendency both for fewer storms to cause run-off from the well-vegetated area and for these few to produce less run-off.

The sediment carried in each 1,000 cubic feet of water is only slightly greater from the depleted plat. The fifth and ninth columns in Table 3 show these figures to be 64.5 and 56.3 cubic feet of sediment for the depleted and the well-covered areas, respectively.

Table 4 also emphasizes the distinct tendency of larger run-offs to be less rich in sediment.

WINTER PRECIPITATION

With plant cover playing such an important part in reducing run-off and soil erosion by summer rainfall, the effect of plant cover on melted snow run-off and erosion deserves attention. In Table 5 are presented the snow survey data for snow depth and water content, and the precipitation subsequent to the snow survey which gives the total water supply in inches and in cubic feet to the acre for the years 1916–21 and 1926–29. There were nearly 2 inches deeper snow and 1.7 inches more water on the depleted watershed, which totals an excess of about 6,000 cubic feet of water to the acre on this area. The opportunities for the drifting of snow probably account for most of this difference. The average date at which run-off ceased was 20 days earlier on the well-vegetated area, indicating a greater absorption of water from the later melted snow. Larger drifts on the depleted area also made for later run-off.

TABLE 5.—*The amount of water in accumulated snow and in spring precipitation available on each watershed for spring run-off, together with the date of snow survey and the date when melted-snow run-off ceased.*

Year	Date of snow survey	Average depth of snow, inches	Average water content, inches	Date run-off ended	Precipitation,* inches	Average total water supply	
						Depth, inches	Per acre, cu. ft.
			Watershed A				
1916..	Mar. 22	30.87	9.20	July 4	1.74	10.94	39,712
1917..	Apr. 25	31.73	9.85	July 17	8.87	18.72	67,954
1918..	Apr. 20	36.67	14.29	July 3	1.81	16.10	58,443
1919..	Apr. 18	41.00	13.29	June 7	0.55	13.84	50,239
1920..	Apr. 30	69.33	20.64	July 10	0.75	21.39	77,646
1921..	May 4	50.10	13.37	July 5	1.10	14.47	52,526
1926..	Apr. 26	29.33	8.73	June 17	1.42	10.15	36,844
1927..	Apr. 30	42.67	14.67	July 3	0.38	15.05	54,632
1928..	Apr. 29	37.69	15.03	June 30	3.07	18.10	65,702
1929..	May 6	52.67	18.88	July 16	1.30	20.18	73,253
Aver..	——	42.21	13.80	July 2	2.10	15.89	57,695
			Watershed B				
1916..	Mar. 22	31.77	9.09	June 9	1.56	10.65	38,660
1917..	Apr. 25	24.53	8.00	June 24	8.87	16.87	61,238
1918..	Apr. 20	38.07	14.45	June 10	1.81	16.26	59,024
1919..	Apr. 18	43.00	13.94	June 4	——	13.94	50,602
1920..	Apr. 30	57.20	17.00	June 15	0.75	17.75	64,432
1921..	May 4	54.10	15.85	June 10	1.10	16.95	61,528
1926..	Apr. 26	29.53	7.87	June 4	1.42	9.29	33,723
1927..	Apr. 30	33.64	13.18	June 14	0.38	13.56	49,223
1928..	Apr. 29	31.04	9.16	June 7	2.24	11.40	41,382
1929..	May 6	51.36	13.71	June 24	1.57	15.28	55,466
Aver..	——	39.42	12.22	June 12	1.97	14.20	51,528

*Average precipitation from date of survey to end of run-off.

In Table 6 is given a summary of the data for melted snow run-off and the sediment carried for the years in which the data were taken, *viz.*, 1916–19 and 1926–29, on the formerly depleted area, and for 1919 and 1926–29 on the area with a good plant cover. Averages are presented for the four years, 1926–29, in order to permit comparisons.

TABLE 6.—*Summary of melted snow run-off and erosion in two different periods on watersheds A and B.*

Year	Average available water supply per acre, cu. ft.	Date run-off began	Date run-off ended	Surface run-off per acre		Sediment per acre, cu. ft.	Sediment per 1,000 cu. ft. of run-off, cu. ft.
				Cu. ft.	%		
			Watershed A				
1916..	39,712	Apr. 29	July 4	27,210	68.5	22.67	0.833
1918..	58,443	Apr. 29	July 3	40,151	68.7	31.50	0.785
1919..	50,239	Apr. 23	June 7	16,145	32.1	28.63	1.773
Aver.	49,465	Apr. 27	June 25	27,835	56.3	27.60	0.992
1926..	36,844	Apr. 24	June 17	31,916	86.6	16.63	0.521
1927..	54,632	May 13	July 3	27,873	51.0	9.14	0.328
1928..	65,703	Apr. 29	June 30	36,486	55.5	17.35	0.476
1929..	73,253	May 7	July 16	42,494	58.0	16.01	0.377
Aver..	57,608	May 3	July 2	34,692	60.2	14.78	0.426
			Watershed B				
1919..	50,602	Apr. 23	June 4	11,502	22.7	32.91	2.861
1926..	33,723	Apr. 24	June 4	9,037	26.8	10.42	1.153
1927..	49,223	Apr. 30	June 14	3,328	6.8	8.14	2.446
1928..	41,382	Apr. 29	June 7	15,006	36.3	20.72	1.381
1929..	55,466	May 7	June 24	3,769	6.8	1.87	0.496
Aver..	44,948	Apr. 30	June 12	7,785	17.3	10.29	1.322

The total water supply on each acre differs considerably, the average being 57,608 cubic feet for the poorly covered watershed and 44,498 cubic feet for the well-vegetated one. Run-off began at approximately the same time on both areas each year, but continued 20 days later from the newly vegetated watershed from which 60% of the available water ran off as compared with 17% from the well-vegetated one. While snow drifting influenced the lateness of run-off, the wide difference between 60 and 17% indicates a vast difference in water absorption, due in a large measure to the better soil on the continuously well-vegetated area.

Table 3 showed 913 cubic feet of run-off an acre from summer rainfall on the depleted area during 1915–20. Table 6 shows that the average annual run-off from melting snow in 1916, 1918, and

1919 was 27,835 cubic feet an acre and that it carried an average of 28 cubic feet of sediment. During the period of 1926–29, inclusive, after the plant cover was improved, the average annual run-off from each acre was 297 cubic feet from summer rainfall and 34,692 cubic feet from melted snow. The melted snow run-off carried only 15 cubic feet of sediment to the acre. On the older vegetated area the yearly run-off was 7,785 cubic feet which carried 10 cubic feet of sediment.

Thus, only 4.6% of the average total annual run-off from the watershed with a 16% cover was from summer rains as compared to 95.4% from melted snow. The 4.6% which was summer rainfall run-off, however, carried an average of 80.1%, or about 5 times, as much of the sediment eroded annually as did the 95.4% melted snow run-off. Later, when the plant cover was increased to 40%, the run-off from summer rains was only 1.3% of the total. The erosion due to melted snow run-off was decreased 46% and the amount of sediment carried per 1,000 cubic feet of run-off water was reduced 57% as a result of increasing the plant cover. The water run-off from melted snow, however, was greater during the later period by almost 7,000 cubic feet to the acre.

ERODED VS. NON-ERODED SOILS

By 1927, the soils on the newly vegetated area differed so widely from one place to another as to suggest a close relationship between the quality of the soil and the kind of vegetation produced. Where the vegetation was poorest it was noted that the soils appeared to be raw and unproductive. This was studied in the field during the latter part of June and early July, 1927. The tentative conclusion from these field studies was that wide differences in the organic matter of the various soils bore an intimate relationship to the kind of vegetation they could support. Accordingly, seven soil samples, each composited from five individual samples, were taken in different vegetative conditions and in places where different degrees of erosion were readily discernible.

The soil samples were later tested in the laboratory for total nitrogen content and for water-soluble phosphorus. the data from the seven samples are summarized in Table 7. These samples were numbered along with some others and the sample numbers are included in the table for convenience.

Samples 3, 5, and 30 were taken in spots where there was a good growth of wheatgrass and of perennial weeds palatable to livestock, here designated as "good weeds." The total nitrogen contents of the

three samples were 0.354, 0.316, and 0.340, respectively. The water-soluble phosphorus determinations gave 0.48, 0.80, and 0.28 p. p. m.

TABLE 7.—*Total nitrogen and water-soluble phosphorus in seven soil samples taken from well-preserved, moderately eroded, and badly eroded spots, together with the plants supported by the various soils, on a newly vegetated watershed, 1927.*

Sample No.	Erosion condition		Total N, %	Available phosphorus, p.p.m.
	Plant cover	Soil		
3	Grass abundant, all young; good perennial weeds	Little erosion	0.354	0.48
5	Grass abundant, old and young; good perennial weeds	Little erosion	0.316	0.80
30	Grass abundant, old and young	Little erosion	0.340	0.28
1	Perennial weeds	Surface eroded; no gullies	0.236	0.40
4	Good perennial weeds; some grass, but not increasing from year to year	Surface gone; clay weathered	0.280	0.44
2	Annual weeds	Heavily eroded; samples from exposed subsoil on sides of gullies	0.088	0.24
27	None	Wind-accumulated soil at base of alpine fir	0.251	1.68

Sample 1 came from a spot where no grass was growing but where the perennial weeds were thrifty and abundant. The dark surface soil was largely gone, but no gullies were formed. This sample showed 0.236% nitrogen and 0.40 p. p. m. water-soluble phosphorus. Sample 4 was taken from a spot previously stripped of its top soil, exposing the clay sub-soil, but which had weathered until it was friable. It had begun to accumulate some organic matter. There were some grass plants among an abundant growth of perennial weeds. The grass was neither gaining nor receding in proportions from year to year so far as could be seen. There were 0.280 per cent total nitrogen and 0.44 p. p. m. water-soluble phosphorus in this sample.

On the other hand, sample 2 came from a badly eroded gully edge from which all the dark surface soil and most of the more friable clay subsoil had been removed. Only annual weeds and mountain lily (*Erythronium sp.*) were found on this soil, and these very sparsely. The nitrogen content of this soil was 0.088% and the water-soluble phosphorus 0.24 p. p. m.

Along the upper margin of the same experimental watershed, at the base of some alpine fir trees, there were deposits a few inches deep of

dark wind-accumulated soil. No plants had yet occupied this soil. Sample 27 from this soil tested 0.251% nitrogen and 1.68 p. p. m. water-soluble phosphorus.

There appears not to be a very close relationship between the available phosphorus and the apparent degree of erosion of these soils. One of the most productive and least eroded soils contained only 0.28 p.p.m., whereas the sample from the badly eroded soil showed 0.24 p.p.m. The other soils carried 0.48 and 0.80 p.p.m. for non-eroded soils and 0.44 and 0.40 p.p.m. for partly eroded soils. The percentage of total nitrogen, however, showed that sharp contrasts in nitrogen content accompanied sharp contrasts in vegetation and in degree of surface erosion. The three soils on which there was considerable grass among the good annual weeds had an average nitrogen content of 0.337%. Since the wind-accumulated soil supported no vegetation, it has no definite importance in this study, but was thought to be interesting in that it represented what was being moved by wind. Since this soil was rather heavy in weight, perhaps the lighter-weight and more distinctly organic material was not being deposited here.

About 2 miles down the canyon, where it widens out, is an alluvial slope of low gradient, locally known as Bluebell Flat. The upper side of this area has been well preserved for many years, whereas near the creek is an area which had been heavily grazed and on which there had been sufficient erosion to remove much, but not all, of the dark-colored top soil. About a quarter of a mile farther up the canyon a road crosses the creek and after a reverse curve cuts along a side hill for approximately half a mile. This road is cut into the side of the steep slope and part of the distance runs just beneath an open stand of aspen with a good under-growth of many-flowered bromegrass and other herbaceous plants. Near the upper end of the cut, the fine dark surface soil from the slope above for seven years had been creeping down over the steep slope of the cut above the road.

Two composite soil samples drawn from Bluebell Flat and three from along the road cut were analyzed in the laboratory for total nitrogen and for water-soluble phosphorus. These data, along with notes on the plants and general soil conditions, are given in Table 8.

Sample 25 was taken on the well-preserved area of gentle slope where, at the time the study was made, two grasses, many-flowered brome and onion grass (*Melica sp.*), were abundant and niggerhead (*Rudbeckia occidentalis*), a composite, was common, but where a few years previously there had been a particularly vigorous growth of pentstemon (*P. rydbergii*), giving rise to the name "Bluebell Flat."

This species recently had become somewhat subordinated by the grasses. The soil was dark brown in color, rich in organic matter, and friable. No visible erosion had occurred here. Its nitrogen content proved to be 0.337% and its water-soluble phosphorus 1.00 p.p.m.

TABLE 8.—*Total nitrogen and water-soluble phosphorus in soil samples taken from a well-preserved area, from a partly eroded area, and from the slope of a road cut.*

Sample No.	Erosion condition		Total N, %	Available phosphorus, p.p.m.
	Plant cover	Soil		
25	Perennial weeds abundant; many-flowered bromegrass and onion grass abundant	Soil in process of building; no erosion	0.337	1.00
26	Some perennial weeds and many annual weeds	Surface considerably eroded; no gullies	0.202	0.32
21	Young many-flowered bromegrass and onion-grass abundant	Dark soil accumulated from slope above road cut	0.427	0.44
22	Few knotweeds nearly bare	Clay side of road cut	0.043	0.20
23	Dense growth of large grass	Soil a black loam very rich in organic matter	0.383	0.44

Sample 26 was collected on the lower edge of the slope where soil conditions similar to those above had once prevailed, but where heavy grazing had damaged the grasses and permitted erosion of much but not all of the dark surface soil. Only the upper 2 inches of soil were friable, and the clayey sub-soil contained only moderate amounts of organic matter. There were few grass plants and some pentstemon, but a large number of small weeds, principally chickweed (*Alsine jamesiana*). This soil showed 0.202% total nitrogen and 0.32 p.p.m. water-soluble phosphorus.

Sample 21 came from the slope of the road cut and comprised the surface 7 inches of dark (almost black) fine-grained soil very rich in organic matter, all of which had crept down over the brink of the road cut from the aspen forest above, which was fully occupied by brome and melic grasses and some niggerhead. Young grass plants had established themselves in profusion on this recently accumulated soil on the road cut, showing that conditions were highly favorable. This soil had a total nitrogen content of 0.427% and a water-soluble phosphorus content of 0.44 p.p.m.

About 200 feet down the road a bank of white raw clay was exposed which had not been covered by creep from above. No grass

and no perennial weeds occurred here, there being only a small growth of annual weeds, chiefly knotweed. Sample 22 from the surface 7 inches of this artificially exposed bank contained 0.043% nitrogen and 0.20 p.p.m. of water-soluble phosphorus.

In another part of the road cut there was an abundance of creep from above and it was occupied by mature full-sized plants, chiefly bromegrass. This soil seemed even richer in organic matter than did sample 21, but an analysis showed 0.383% total nitrogen as compared with 0.427% for sample 21. The water-soluble phosphorus amounted to 0.44 p.p.m.

These soil samples corroborate the data from the experimental watershed. The uneroded dark surface soil on Bluebell Flat and the dark surface creep along the dugway showed 0.337, 0.427, and 0.383% nitrogen, respectively, which is an average of 0.382%. On all of these soils good grasses were abundant and thriving. The partly eroded soil with only an occasional grass plant but with a considerable weed growth contained 0.202% nitrogen as compared with 0.043% on the artificially-exposed raw clay where only a few annual weeds grew. The water-soluble phosphorus showed a moderately consistent relationship to the erosion and to the plants supported. The three good soils contained 1.00, 0.44, and 0.44 p.p.m., as compared with 0.32 and 0.20 p.p.m. for the moderately eroded and the bare raw clay, respectively.

SUMMARY

On the elevated grazing lands of central Utah, surface run-off and the sediment carried have been studied since 1915. Two nearby experimental watersheds of approximately equal area, at an elevation of about 10,000 feet, and so located and equipped as to permit the measurement of the precipitation, the run-off water, and the sediment carried, differed widely in their plant cover. One of these with a considerably eroded soil supported from 1915 to 1920, inclusive, a plant cover of 16%. During 1921, 1922, and 1923 the plant cover was increased to 40% and has been maintained until the present. The other watershed with a little-eroded soil had a well-established plant cover of 40% throughout the period under study.

Rain gauges on the two areas showed a slightly greater summer precipitation on the area that was well vegetated from the beginning, and yet the run-off caused by summer rainfall was 5.96, 3.54, and 2.16 times as great for the three periods of 1915–20, 1921–23, and 1925–29, respectively, from the area at first poorly vegetated. The sediment removed was about in the same proportion, *viz.*, 5.42, 2.82, and 2.48, respectively, for the three periods. There was, however,

little difference in the sediment carried in each 1,000 cubic feet of surface run-off. Roughly, 3 to 5 times as much total water ran off the area with the poorer plant cover. For the three periods of years above noted, the run-off was 10.33, 8.74, and 5.49% of the total rainfall on the area with the poorer plant cover as compared with 4.10, 2.88, and 1.05% for the continuously well-vegetated area.

Approximately two-thirds of the total precipitation came as snow and fully half the total was available for spring run-off from melted snow and from spring rains which came while the snow was melting. Run-off began at the same time on the two watersheds but ceased 20 days earlier on the one that was well-vegetated from the beginning. During the years 1926–29, inclusive, 60.2% of the total water available for spring run-off actually ran off the formerly depleted watershed, but only 17.3% from the well-vegetated one. If the years 1916–18, when one area had a 16% plant cover, are compared to the years 1926–29 when the same area had a new 40% cover, the total sediment eroded decreased 46% and the amount carried in each 1,000 cubic feet of run-off water decreased 57%, due to improving the plant cover.

Of the total run-off from the depleted area during 1915–20, 4.6% was due to summer rainfall and 95.4% due to melted snow. The summer rainfall, however, carried 80.1% of the total sediment removed. After the plant cover had improved to 40%, only 1.3% of the total run-off resulted from summer rains.

Eroded and non-eroded soils were compared on the newly vegetated watershed and on another area about 2 miles away. The non-eroded, dark-colored surface soil of the newly vegetated watershed contained on the average 0.337% nitrogen as compared to 0.258% and 0.088% on the partly eroded and badly eroded areas, respectively. The badly eroded soils supported only annuals or non-palatable perennials, while the partly eroded soils supported palatable perennial plants and the non-eroded soils a good growth of forage grasses in addition to palatable perennials.

The other area 2 miles away showed 0.382% nitrogen for uneroded dark-colored soils which supported grasses, 0.202% for the partly eroded soils which supported only poor perennial plants, and 0.043% on the exposed raw clay subsoil of a road cut which produced after 7 years only a few annual knotweeds.

Water-soluble phosphorus was not found to be as closely related to the degree of soil erosion or to the kind of plants supported. Phosphorus is probably not a limiting plant nutrient on these soils.

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THE DETERMINATION OF REPLACEABLE HYDROGEN IN MANGANESE DIOXIDE-FREE HAWAIIAN PINEAPPLE SOILS[1]

L. A. DEAN and O. C. MAGISTAD[2]

An accurate yet simple method for routine determinations of replaceable hydrogen in soils is needed where agricultural practices are scientifically controlled. Such a method will enable one to follow, on a large scale, the changes brought about by the use of physiologically acid and alkaline fertilizers; will serve as a guide in liming practices; and will also enable one to compare one soil with another in respect to certain of its chemical and physical properties.

Since the determination of replaceable hydrogen is somewhat dependent upon its arbitrary definition, we have defined replaceable hydrogen as that quantity of hydrogen in a soil (expressed in milligram equivalents per 100 grams) which if replaced by calcium will cause the soil to have a reaction of pH 7.0.

Rarely in agricultural practice is a soil purposely brought to a pH value above 7.0. Analytical methods which determine the replaceable hydrogen between the original pH value and pH 9.0, for instance, are undesirable because the fraction of replaceable hydrogen liberated between pH 7.0 and pH 9.0 is not, on a series of soils, a constant fraction of the whole, nor is it the same on all soils from the same region. Calcium is selected as the proper cation to use in replaceable

[1]Technical paper No. 23 of the Experiment Station of the Association of Hawaiian Pineapple Canners, University of Hawaii, Honolulu, T. H. Received for publication March 23, 1931.

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hydrogen determination because (a) calcium constitutes the major exchangeable cation in natural neutral soils, and because (b) calcium-bearing materials are practically always used for the purpose of increasing soil reaction values.

The methods of determining replaceable hydrogen which already have been proposed in the literature may be divided into the following three classes:

1. The difference method as proposed by Kelley (6)[3].
2. The methods whereby a known quantity of alkali, for example, barium hydroxide, is added to the soil and the excess titrated, as suggested by Hissink (4), Puri (9), and Behrens (3).
3. The leaching methods, using as a general rule, acetate solutions, as suggested by Parker (7) and Schollenberger and Dreibelbis (11).

EXPERIMENTAL

The difference method was eliminated from consideration because its complications led us to believe that a short routine laboratory method could not be devised using this principle.

Light was thrown on the methods grouped in class 2 above by the following experiment which was based on Hissink's method. Ten grams of soil and 50 cc of a 0.1 N barium hydroxide solution were placed in each of a series of tightly stoppered flasks and shaken at irregular intervals for a period of 4 days. The contents of the flasks were then filtered through a Buchner funnel and washed with hot water. The filtrates were made acid, boiled, and back titrated, using methyl red as an indicator. The results are given in Table 1.

TABLE 1.—*The quantity of replaceable hydrogen in certain Hawaiian soils as determined by a modification of Hissink's method.*

Soil No.	M.E. H per 100 grams soil	pH of residual soil
554	37.7	10.22
555	52.6	9.42
626	50.4	9.23
631	54.7	9.42

These data show that this method gives the replaceable hydrogen to a point considerably above pH 7.0, and that in only one case was there probably sufficient barium hydroxide to react with all of the replaceable hydrogen up to the pH of 0.1 N barium hydroxide. In view of the above and of the fact that we have defined replaceable hydrogen as that hydrogen replaced up to pH 7.0, it seems unlikely that a successful method of this type can be developed to satisfy our definition.

[3]Reference by number is to "Literature Cited," p. 243.

EFFECT OF NATURE OF CATIONS IN REPLACING SOLUTION

Parker (7), working with neutral barium acetate solutions, and Schollenberger and Dreibelbis (11), working with ammonium acetate solutions, have indicated that replaceable hydrogen to pH 7.0 can be determined by leaching soils with their respective reagents.

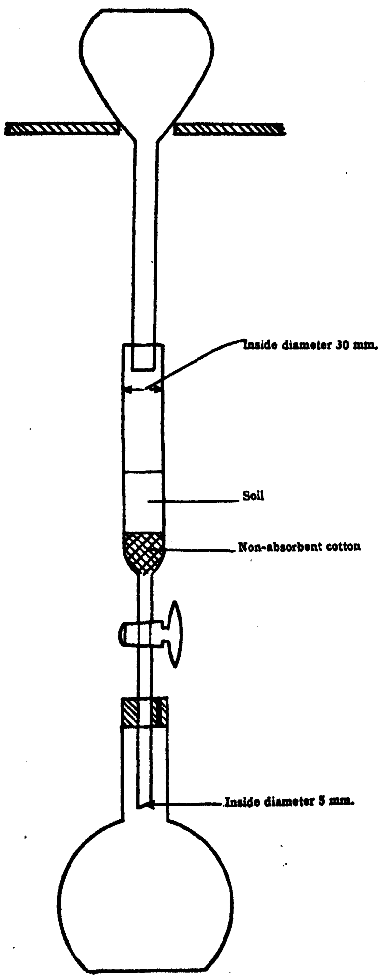

FIG. 1.—Diagram showing the leaching apparatus used.

In order to determine the relative merits of the different acetate solutions for the purpose of replacing hydrogen, the following series of determinations was made. Using samples of the same soil (No. 626), 20-gram portions were placed in a series of leaching tubes of the type shown in Fig. 1, and leached with 1,500 cc of 0.5 N barium calcium, and sodium acetates and 1.0 N ammonium acetate at the rate of 15 drops per minute. These solutions had pH values as given in Table 2.

Aliquots of the leachates were boiled[4], cooled, and titrated electrometrically to pH 7.0, using a quinhydrone electrode. Using the hydrogen electrode, pH determinations were made on each soil at the completion of the leaching process while it was still in equilibrium with the leaching reagent. After the reagent had been washed out, pH values were again determined, using varying amounts of distilled water where barium and calcium acetates had been used and neutral 95% denatured alcohol where the ammonium and sodium salts had been used. Determinations of pH values were made always on soil suspensions in which the ratio of soil to liquid was 1:2.

[4]The ammonium acetate leachate was not boiled because on boiling it decomposes giving off NH_3.

These data show that when samples of the same soil are leached with acetate solutions of various cations, the amount of replaceable hydrogen varies with the cation used. They also show that when a neutral acetate solution is leached through a soil and the residual soil washed free from the leaching solution, the pH of that residual soil is not the same as that of the original leaching solution, and that this pH varies with the different cations present in the acetate leaching solution.

TABLE 2.—*The quantity of replaceable hydrogen in soil 626 as determined by leaching with various acetate solutions.*

Acetate leaching solution used	M.E. H per 100 grams soil	pH original leaching solution	Residual soil pH			
			In presence of leaching solution	Leached with 200 cc H_2O	Leached with 400 cc H_2O	Rise in pH
Ba	22.4	7.00	6.94	7.30	7.44	0.50
Ca	24.2	6.97	6.87	7.14	7.43	0.56
				Leached with 500 cc alcohol	Leached with 1,000 cc alcohol	
NH_4	15.5	7.03	6.98	8.47	8.88	1.90
Na	12.7	7.00	6.80	8.20	8.19	1.39

BUFFER CURVES OF SOIL USED

Data from which to construct buffer curves of the soil used in the experiment reported above were obtained in the following manner. Two series of 10-gram samples of the same soil were placed in flasks and increasing amounts of 0.04 N calcium hydroxide were added to one set and of 0.072 N sodium hydroxide to the other. The flasks were stoppered and shaken at irregular intervals for a period of a week. The pH of each soil suspension was then determined by means of a hydrogen electrode, using the procedure given by de'Sigmond (12). This method of determining buffer action is similar to the method outlined by Pierre (8).

Buffer curves (Fig. 2) were then constructed by plotting milligram equivalents of each cation added, per 100 grams of soil, against pH values. The number of milligram equivalents of either base required to bring 100 grams of this soil to any pH may be read from these curves, and such numbers were used in our studies of methods of determining replaceable hydrogen as the criteria of correctness.

The buffer curves substantiate and illuminate the results given in Table 2, and furthermore, they show that when equivalent quan-

tities of different cations were used to replace the hydrogen in this soil, different values for replaceable hydrogen were obtained. These results are comparable to those which have been previously reported by Anderson (1) and Baver (2). The latter has attributed this phenomenon to the difference in hydration of the various cations, and to consequent differences in the surface dissociation. Since different cations give different values for replaceable hydrogen, and

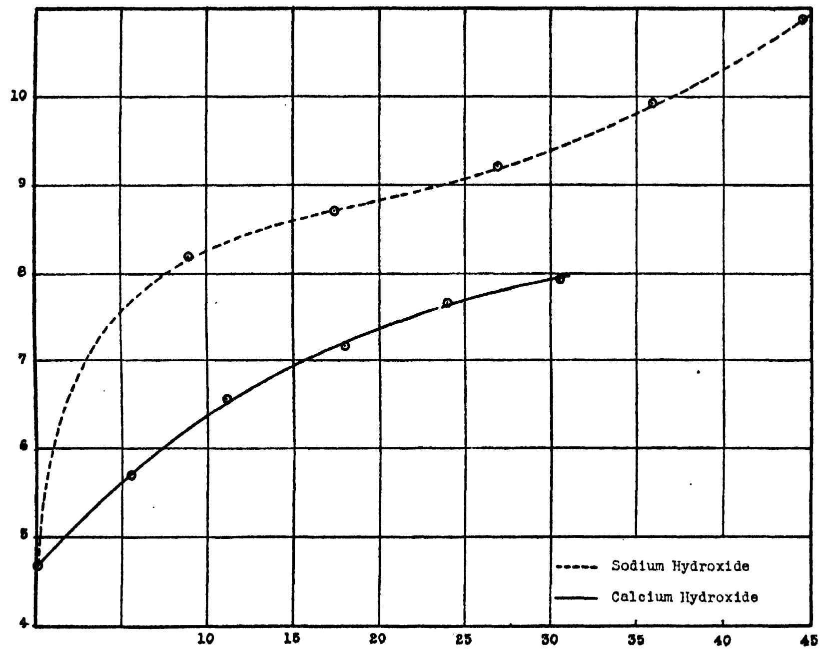

FIG. 2.—Buffer curves of soil 626 as determined by the use of calcium and sodium hydroxides.

in view of the fact that calcium compounds are used in the vast majority of the attempts to neutralize acid soils, it is logical to assume that calcium should be the cation to employ in the determination of replaceable hydrogen. Kappan (5) has already expressed this same opinion.

The cost of barium reagents is great compared with the cost of equivalent calcium reagents. In laboratories where great numbers of replaceable hydrogen determinations are made, such as ours, this cost difference becomes an important factor.

PH VALUE OF THE RESIDUAL SOIL

When a soil is leached with a neutral calcium acetate solution until the solution has replaced all of the hydrogen which it possibly

can, the pH of the residual soil is not the same as that of the original leaching solution. This called for further study. A portion of the soil used in the tests described above was leached with 0.5 N calcium acetate having a pH value of 7.00 in the previously described manner. The pH of the residual soil was determined after successive washings with water, and the liquid of the suspension in which the pH was determined was analyzed for calcium. From these data the ratios of calcium to hydrogen ions in the liquids of the suspensions were determined. The results obtained are given in Table 3.

TABLE 3.—*The relationship between degree of leaching of soil residues, the composition of the soil solution, and pH values.*

	(1) In presence of original solution	(2) Leached with 200 cc H_2O	(3) Leached with 400 cc H_2O	(4) Leached with 600 cc H_2O	(5) Leached with 800 cc H_2O
pH	6.87	7.14	7.50	7.32	7.22
p.p.m. Ca in solution......	1×10^4	96	19	16	12
Ratio $\frac{\text{Ca ions}}{\text{H ions}}$............	1.5×10^6	3.3×10^4	1.5×10^4	8.3×10^3	5.0×10^3

M.E. replaceable hydrogen per 100 grams soil = 23.8.

The data in Table 3 show that a soil which has been leached for a period with calcium acetate has a pH value of 6.87 in the presence of the leaching solution. Let us picture conditions at this stage, which can be called stage 1. These data show that the H ion concentration was $1 \times 10^{-6.87}$ gram equivalents per liter. We know that the concentration of calcium and acetate ions was approximately 0.5 equivalents per liter. Using the value 1.8×10^{-5} as the dissociation constant of acetic acid, we are enabled to calculate the concentration of undissociated acetic acid in the solution. Such calculations were also made for stages 2 and 3 from the data in columns 2 and 3. These data appear in Table 4.

TABLE 4.—*The approximate concentration of H, OH, Ca, and acetate ions in the solution bathing the soil particle after successive washings with the concentration of undissociated acetic acid.*

Ion or acid	Concentration in equivalents per liter		
	Stage 1	Stage 2	Stage 3
H..................................	$1 \times 10^{-6.87}$	$1 \times 10^{-7.14}$	$1 \times 10^{-7.50}$
OH................................	$1 \times 10^{-7.13}$	$1 \times 10^{-6.86}$	$1 \times 10^{-6.50}$
Ca.................................	0.5	4.8×10^{-3}	1×10^{-3}
Acetate ion.......................	0.5	4.8×10^{-3}	about 1×10^{-3}
Undissociated acetic acid..............	about 2.8×10^{-3}	about 2.0×10^{-5}	about 1.8×10^{-6}

Table 4 shows the quantity of Ca ions, acetate ions, and undissociated acetic acid removed with successive leachings. Their removal causes a marked decrease in the buffering capacity of the bathing liquid. As a result, in stage 3, where little buffer is present, the true pH of the soil residue is approached. The continuous line in Fig. 3 indicates the change in pH value with progressive washing.

It appears from Table 3 that the pH of the soil in equilibrium with the calcium acetate solution was 6.87, and that when this acetate solution had been removed by water to the point of maximum pH, this value has risen to 7.50. By referring to Fig. 2 it may be seen that a pH of 6.87 corresponds to 14.8 milligram equivalents of replaceable hydrogen when calcium is used as the replacing agent and that pH 7.50 corresponds to 22.0 M. E. The value of 23.8 milligram equivalents of replaceable hydrogen determined by titrating the calcium acetate leachate, and recorded in Table 3, corresponds to pH 7.65. It may be inferred, therefore, that the maximum pH value found, i. e., 7.50, was not the true maximum because of the effects of hydrolysis which set in during washing.

If no hydrolysis had set in, progressive leaching of the soil should have given a final pH value of 7.65. The theoretical change of pH value with progressive leaching is indicated by the left-hand dotted line in Fig. 3.

Considering a calcium-saturated soil in equilibrium with an acetate-free soil solution, the solution will contain a number of calcium ions and a few hydrogen ions. It may be assumed that the soil after leaching with 400 cc of water (Table 3, column 3) is practically free of acetates. The ratio of calcium ions to hydrogen ions in the soil solution at this stage is 1.5×10^4. In other words, there are 15,000 times as many calcium ions as hydrogen ions in the soil solution at this stage. On further leaching with water many of these calcium ions are removed. Thus, in the next stage, there are only 8,300 times as many calcium ions as hydrogen ions. With a greater relative number of hydrogen ions there is a greater possibility for the hydrogen ions to be at the soil particle at any given moment, looking upon the process as a dynamic equilibrium. Some calcium ions have left the particle to go in solution with a corresponding exchange of hydrogen ions from the solution to the particle. As a result, the concentration of hydrogen ions in the solution is lowered to the extent that the pH value of the suspension is 7.32. Further washing removes still more calcium so that the ratio of calcium ions to hydrogen ions becomes 5,000. The pH value here decreases to 7.22.

If progressive removal of acetates had been accomplished without hydrolysis, the soil suspension should have reached a pH value of 7.65. The change in pH value on hydrolysis of such a theoretical soil would very probably follow the dotted extension of the hydrolysis curve in Fig. 3.

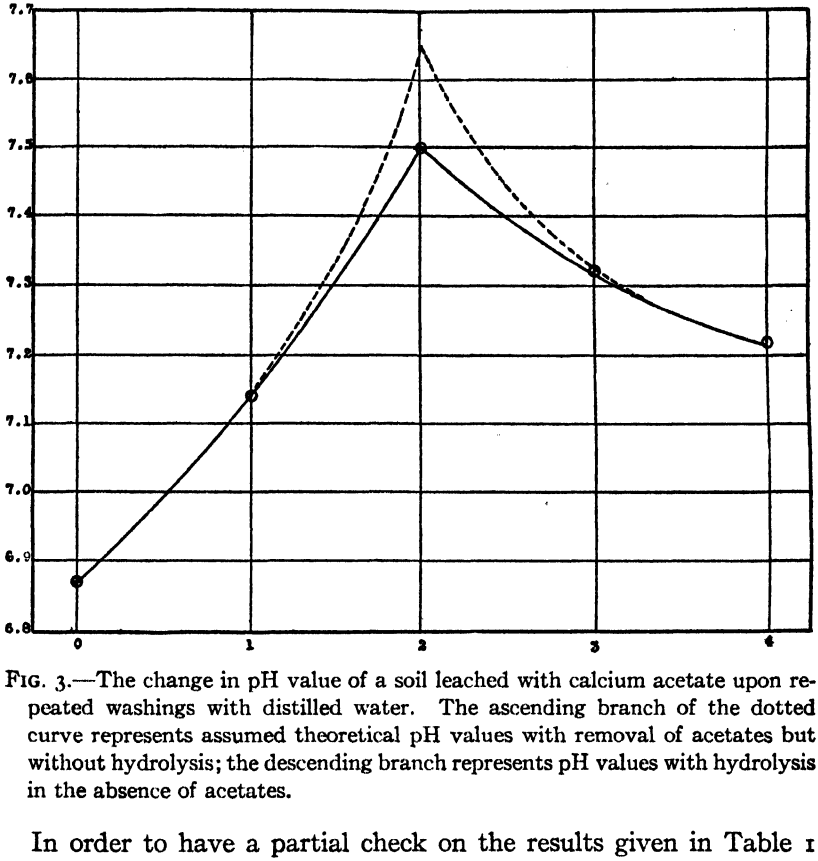

FIG. 3.—The change in pH value of a soil leached with calcium acetate upon repeated washings with distilled water. The ascending branch of the dotted curve represents assumed theoretical pH values with removal of acetates but without hydrolysis; the descending branch represents pH values with hydrolysis in the absence of acetates.

In order to have a partial check on the results given in Table 1 and also to compare the use of different acetate leaching solutions in the determination of replaceable hydrogen, the following experiment was conducted. Samples of different soils were leached with 0.5 N calcium and N ammonium acetate solutions in the previously described manner. These leaching solutions were adjusted to a pH of about 6.5. The residual soil pH was also determined after leaching with 500 cc of water in the case of calcium and neutral methyl alcohol in the case of ammonium acetate. The results are given in Table 5.

The data in Table 5 are in accord with those shown in Table 1. They also show that when a soil is leached with a calcium acetate

solution of pH 6.5, the exchangeable hydrogen is replaced to approximately pH 7.0. This indicates that if we accept calcium as the proper cation to use, Schollenberger's method (11) is inaccurate and the results obtained by it are too low.

TABLE 5.—*A comparison of calcium and ammonium acetates as leaching reagents.*

Soil No.	Calcium acetate			Ammonium acetate			Difference M.E./100 grams soil
	pH original solution	pH residual soil	M.E. H per 100 grams soil	pH original solution	pH residual soil	M.E. H per 100 grams soil	
633	6.50	6.97	10.2	6.58	8.25	7.1	3.1
634	6.50	6.95	14.0	6.58	8.25	10.2	3.7
876	6.50	6.96	15.8	6.58	8.25	11.8	4.0
631*	6.50	6.95	18.2	6.58	8.25	13.3	4.9
875	6.50	6.99	18.8	6.58	8.25	12.6	6.2

*Soil 631 contains manganese dioxide.

VOLUME OF REPLACING SOLUTION AND RATE OF LEACHING

In any procedure adopted for the rapid and accurate determination of replaceable hydrogen in soils it is desirable to use at least 20 grams of soil because of the errors which are likely to arise due to the heterogeneous character of soil. To test the possibilities of a shaking method instead of the leaching procedure, the following tests were carried out. Six 20-gram samples of soil 626 which had passed a 20-mesh sieve were placed in liter bottles and 500 cc of 0.5 N calcium acetate solution added to each. The bottles were then shaken in a mechanical shaker for a half hour and the contents allowed to settle over night. The supernatant liquids were then decanted off. Bottle No. 1 was then discarded. To the soil in each of the other five bottles 500 cc of calcium acetate were again added and the shaking and settling procedures repeated. The supernatant liquids from each bottle were again decanted and each one added to the corresponding portion from the first day. The procedure was carried out in such a manner that solutions were obtained which had been derived by shaking from one to six times with the same soil. These solutions were then titrated with the results given in Table 6.

These results show that it would take at least six shakings with successive portions of fresh calcium acetate solution, requiring a total of 3 liters, to replace all of the exchangeable hydrogen in a soil when this method is employed. Leaching is probably the quicker and more thorough method.

Another test was carried out in which the volume of calcium acetate leached through a soil and the rate of leaching were each

varied. Twenty-gram portions of soil were placed in leaching tubes similar to the one shown in Fig. 1 and leached with varying quantities and at different rates. The pH value of the leaching solution was 6.5.

TABLE 6.—*Replaceable hydrogen by the shaking method.*

No. of times shaken	Cumulative volume of replacing solution used, cc	M.E. H replaced per 100 grams soil	M.E. H replaced by additional treatment
1	500	11.8	—
2	1,000	14.6	2.8
3	1,500	16.0	1.4
4	2,000	16.8	0.8
5	2,500	17.5	0.7
6	3,000	17.7	0.2

pH calcium acetate solution = 6.62
M.E. H per 100 grams soil by leaching = 17.9

The data in Table 7 indicate that when 20 grams of soil are leached with 1,500 cc of 0.5 N calcium acetate solution at the rate of 15 drops per minute approximately 98% of the total exchangeable hydrogen is replaced. The rate of leaching appears to be an important factor in replacing hydrogen by calcium.

TABLE 7.—*Effects of varying rates of leaching and quantities of leaching solution.*

Volume of solution leached, cc	Rate leached in drops per minute	M.E. H per 100 grams soil
	Soil No. 631	
1,000	15	13.6
1,500	15	19.9
1,500	30	19.5
1,500	60	17.3
2,000	15	20.3
	Soil No. 626	
1,000	15	11.5
1,500	15	16.9
1,500	30	17.0
1,500	60	14.7
2,000	15	17.4

Parker (7) by the use of 250 cc neutral barium acetate per 5 or 10 grams of soil obtained soil residues which, when washed free of barium acetate, had pH values ranging from 6.87 to 7.25. The present work indicates that had he leached his soil with larger quantities of barium acetate more replaceable hydrogen would have been obtained and the soil residues would have had a greater final pH value. When a series of soils was leached sufficiently with neutral

barium acetate, the pH values of the washed residual soils varied within a narrow range about pH 7.45, as indicated in Table 8. In this work 10 grams of soil were leached with 800 cc of 0.5 N barium acetate solution. The rate of leaching was not controlled.

TABLE 8.—*The pH values of soils leached with 0.5 N barium acetate after removal of residual salt by washing with water.**

Soil No.	pH value leached and washed soil residue
631	7.45
636	7.53
621	7.40
919	7.52
913	7.48
917	7.41
918	7.44
626	7.44

*The barium acetate solution had an initial pH value of 6.98.

We believe that barium is so similar to calcium that errors through its use in place of calcium are small. It would seem highly desirable, however, in view of the great buffer capacity of some soils in the region of pH 7.0, to treat soils in such a way that their residual pH, in all cases, approaches this figure closely. This can be accomplished by leaching slowly with a large volume of 0.5 N calcium acetate having an initial pH value of 6.50 or 0.5 N barium acetate with an initial pH value of about 6.6.

PROPOSED METHOD FOR THE DETERMINATION OF REPLACEABLE HYDROGEN

A sample of the soil to be analyzed is tested with a 15% solution of hydrogen peroxide according to Robinson's method (10). If no violent effervescence occurs due to the presence of manganese dioxide the following procedure is applied: Twenty grams of soil are placed in a leaching tube as shown in Fig. 1 and 1,500 cc of 0.5 N calcium acetate adjusted to pH 6.5 are leached through it at the rate of 15 drops per minute. The leachate is then boiled, to drive off the CO_2, and cooled to room temperature. It is then electrometrically titrated with standard calcium hydroxide to the pH of the original leaching solution, using a quinhydrone electrode.

This proposed method, however, is only applicable to soils which do not contain manganese dioxide in any appreciable quantity. Sufficient data have been collected in this laboratory to show that some of the acetate ions of an acetate leaching solution are decomposed by manganese dioxide when the latter is present. This reaction causes an

erroneous result for replaceable hydrogen when it occurs during the process of leaching a soil with an acetate solution. The authors hope to present further information on this subject in a later paper.

SUMMARY

Acetate-leaching solutions having different cations will give different values for replaceable hydrogen.

When an acetate solution is leached through a soil until the maximum amount of hydrogen has been replaced which the solution is capable of removing, and the acetate washed out, the pH of the residual soil is greater than that of the original leaching solution.

Calcium is the logical cation to use in the replacement of hydrogen during the process of determining replaceable hydrogen.

Leaching is more efficient than shaking in the replacing of hydrogen by calcium from a calcium acetate solution.

The quantity of hydrogen replaced from a soil by calcium from a calcium acetate solution is a function of the volume of solution used and the rate of leaching.

A proposed method for determining replaceable hydrogen in manganese dioxide free soils is given.

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EFFECTS OF SORGHUM RESIDUES ON CROP YIELDS[1]

A. D. McKinley[2]

It is generally accepted in the United States that crops planted in the fall after sorghums do not yield as well as when following other crops. This has been proved by practically all the experimental data available, although in exceptional cases larger crop yields have been secured following sorghums than when following corn or certain other crops. Unfortunately, there are few experimental data on the after effects of sorghums on soils or crops in Asia or Africa where the sorghums are said to have originated and where they have been grown for many centuries.

Breazeale (1)[3] states, however, that he was informed that in China sorghum is grown year after year upon the best land, and that no injurious after effects from the crop had been observed.

King (5) made no mention of any harmful after effects of sorghums in writing on Oriental agriculture, and it is possible that the deleterious effects of sorghums are overcome by the systems of soil management used in southeastern Asia.

Sewell (6) lists five possible causes of the injurious effects of sorghums, namely, (a) depletion of minerals, (b) toxic root excretions, (c) toxic products of decay, (d) diseases associated with the crop, and (e) the effects of soil protozoa and other micro-organisms. Another theory which has been rather popular of late is based on the fact that sorghums are richer in easily decomposable carbohydrates than other crops. Sorghum residues, roots and tops, when incorporated with the soil are believed, according to this theory, to supply energy materials for an abundant microflora and the organisms compete with higher plants for the essential elements, especially nitrogen.

Sewell (6), in a comparison of treated and untreated corn soil, obtained a depression in the yield of wheat when he added dried, chopped kafir roots to the soil. He concluded, however, that the difference was not significant.

Breazeale (1) noted that wheat seedlings were able to secure nitrogenous materials for growth from decomposing corn stubble much sooner, and to a larger extent, than from decomposing kafir stubble.

[1]Portion of a thesis submitted to Iowa State College in partial fulfillment of the degree of doctor of philosophy. Received for publication April 13, 1931.

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[3]Reference by number is to "Literature Cited," p. 849.

Conrad (2) ran incubation tests with varying amounts of milo roots mixed with the soil. He found a reduction in nitrates and concluded that sorghum roots brought about a cessation of nitrification. In another experiment, Conrad (3) added different weights of sorghum roots, corn roots, and sucrose to the soil and the yield of barley was found to be depressed with an increase in the amounts of sorghum roots and sucrose added. The quantities of nitrates in the uncropped soils were found to be progressively depressed by increased additions of sorghum roots and sucrose. A naturally inoculated legume, fenugreek, was found to make normal growth.

Wilson and Wilson (7) compared the abilities of corn and sorghum roots to cause nitrate nitrogen to disappear from the soil. The effects were compared when the roots were used in equal quantities by weight and by soluble organic matter content. The sorghum roots caused a more rapid disappearance of supplied nitrates than the corn roots. The numbers of an organism, designated as "guttation," were found to increase more rapidly in the soil containing sorghum roots than in the one containing corn roots. The evolution of carbon dioxide from soils in culture flasks was found to be more rapid when sorghum roots were mixed with the soil.

Gainey (4) measured the amount of carbon dioxide produced from soil mixed with corn and kafir residues which had been collected at different times. He concluded from the relative rates of decomposition of the corn and kafir residues that kafir contains limited quantities of carbonaceous materials which are somewhat more easily oxidized than those found in corn. The detrimental effects upon nitrate nitrogen accumulation were more or less proportional to the rate of carbon dioxide production during the early periods of incubation. In only one of the nine comparisons did the kafir residues exert a more harmful effect upon nitrate nitrogen accumulation than the corn residues.

The question is debatable as to whether the sorghum residues, or both the crops and residues, are responsible for the depressing effects on succeeding crops. Sorghum residues are apparently more harmful than corn residues. The following investigations were planned to obtain more information on the extent of the depressions in crop yields as caused by milo and kafir residues in comparison with those of corn, wheat, and barley.

EXPERIMENTAL

Approximately 30 pounds of sieved, virgin Clarion loam were mixed with each of the various crop residues, placed in 4-gallon pots, seeded to Marquis wheat, and maintained under optimum moisture conditions during the course of the experiment. Part of the wheat and barley roots used in the soil treatments were secured from pots of previous plantings and part were obtained from plants growing in the field. Corn tops and corn roots were taken from plants growing in the field, the tops consisting of plants that were just beginning to send out silks, while the roots were obtained from mature plants. The sorghum residues were obtained from plants grown in the greenhouse, the plants having been in various stages of maturity. In some cases the crop residues were ground in a Wiley mill, while in others they were merely cut into small pieces. Most of the treatments consisted of applications of dry matter at the rate of 1½ tons per acre of 2 million pounds of soil, but treatments were also made with corn and kafir tops at the rate of 3 tons per acre. When the wheat plants had attained a height of about 4 inches they were thinned to a uniform stand of 19 plants to the pot. The crop was harvested when a few of the plants had headed. Growth of the plants indicated an almost complete exhaustion of soil nutrients. This was confirmed at harvest by tests for nitrates, as all pots gave tests for very small amounts. The different soil treatments and the results secured are shown in Table 1.

All of the treatments, with the exception of the 3-ton applications of corn and kafir tops, brought about increased yields over the checks. Ground kafir and corn tops gave smaller yields than the chopped residues. Ground milo tops gave slightly smaller yields than wheat or barley straws and considerably smaller yields than corn or kafir tops, either ground or chopped. The yields were somewhat smaller with the ground milo roots than with the ground corn roots. The results obtained with kafir, wheat, and barley roots differed slightly, but were much higher than with the milo and corn roots. The depressing effects of the 3-ton applications of corn and kafir tops became evident a few weeks after planting and continued throughout the growth of the plants. The kafir tops exerted the greatest depressing effect during the early part of the experiment, but the plants in those pots seemed to grow more rapidly later in the experiment than in the pots which received the corn residues.

This experiment showed that sorghum residues applied to the soil at the rate of 1½ tons of dry matter per acre had varying effects, depending on (a) the kind of plant, (b) whether tops or roots were used,

and (c) the physical condition of the residues. Compared to the checks there was no depression due to sorghum residues (unless added in large amounts), and in some cases materially increased yields occurred.

TABLE 1.—*Comparison of the effects of milo, kafir, corn, wheat, and barley residues on the yield of wheat, the numbers of stems, and the nitrate content of the soil.*

Residues incorporated with soil	Nitrates, p.p.m. at harvest	Yields of wheat			
		Stems		Yield in grams	
		Number	Average	Total	Average
Corn tops ground, 1½ tons	0.93	54	—	76.4	—
	1.59	60	57.0	74.2	75.3
Kafir tops ground, 1½ tons	1.54	43	—	74.8	—
	1.28	50	46.5	74.2	74.5
Milo tops ground, 1½ tons	1.11	52	—	65.1	—
	1.51	55	53.5	65.5	65.3
Wheat straw ground, 1½ tons	1.45	53	—	66.6	—
	1.59	59	56.0	67.5	67.0
Barley straw ground, 1½ tons	0.94	53	—	70.0	—
	1.43	55	54.0	72.5	71.2
Corn tops chopped, 1½ tons	1.55	56	—	83.6	—
	1.22	50	53.0	84.7	84.2
Kafir tops chopped, 1½ tons	1.06	54	—	81.5	—
	5.81	65	59.5	75.0	78.2
Corn tops ground, 3 tons	2.32	56	—	59.9	—
	1.37	52	54.0	58.3	59.1
Kafir tops ground, 3 tons	1.54	45	—	58.3	—
	1.16	48	46.5	54.1	56.2
Corn roots ground, 1½ tons	1.88	55	—	76.3	—
	1.49	58	56.5	70.2	73.2
Kafir roots ground, 1½ tons	1.47	62	—	83.1	—
	1.73	59	60.5	78.3	80.7
Milo roots ground, 1½ tons	1.17	55	—	74.5	—
	1.25	56	55.5	71.0	72.7
Wheat roots ground, 1½ tons	1.39	53	—	81.8	—
	1.43	50	51.5	78.3	80.0
Barley roots ground, 1½ tons	1.05	43	—	83.2	—
	1.11	45	44.0	80.4	81.8
Nothing	1.75	61	—	64.8	—
Nothing	0.98	53	—	63.7	—
Nothing	1.51	51	55.0	59.6	62.7

A similar experiment was undertaken to obtain information on the effects of milo, kafir, wheat, and barley residues on the respective crops. Applications of residues were made at the rate of 1½ tons of cured, chopped materials per acre. The results with kafir and milo are the only ones included in Table 2, as the barley did not grow normally in any of the pots and the wheat was destroyed by rats when the plants were ripening.

The results obtained with kafir and milo are very similar to those obtained in the first experiment with wheat. Although no data were secured on wheat yields, the plants in the sorghum residue

pots were larger and had produced more grain than those in the check pots.

TABLE 2.—*Effects of milo, kafir, wheat, and barley residues on the yields of kafir and milo.*

Residues incorporated with soil	Nitrates, p.p.m. at harvest	Yield in grams	
		Total	Average
Kafir			
Kafir tops	2.70	48.8	
Kafir tops	1.92	51.9	50.3
Milo tops	1.64	45.6	
Milo tops	1.66	56.5	51.0
Wheat straw	1.64	44.1	
Wheat straw	1.92	43.0	43.5
Barley straw	0.79	48.1	
Barley straw	1.61	44.5	46.3
Nothing	2.13	41.5	
Nothing	1.54	46.5	44.0
Milo			
Kafir tops	1.56	45.5	
Kafir tops	1.49	46.1	45.8
Milo tops	2.15	41.1	
Milo tops	1.69	48.2	44.6
Wheat straw	1.49	55.7	
Wheat straw	0.96	51.4	53.5
Barley straw	2.22	49.7	
Barley straw	1.98	46.0	47.8
Nothing	2.86	44.4	
Nothing	2.63	41.1	42.7

DISCUSSION

Conrad (3) believed that the theory of the competition between micro-organisms in the soil and crop plants for nitrogen and possibly other essential elements satisfactorily explains the decreases in yields following sorghums. The results secured in these experiments indicate that sorghum residues in rather large quantities may be a contributing factor, especially in soils which have already been depleted of nutrient elements by heavy crop yields. Some sorghum residues, undoubtedly, contain small quantities of carbonaceous materials which are somewhat more easily oxidized than those that exist in corn, wheat, or barley residues.

Gainey (4) believed, however, that such easily oxidizable materials would soon be exhausted and that the decomposition of corn and

sorghum residues would soon run practically parallel. Gainey's decomposition studies are in accord with the observations made in these investigations and especially with those on the growth of wheat in pots having corn and kafir applications at the rate of 3 tons per acre, as the plants in the kafir residue pots grew as well or better than those in the corn residue pots after the initial period of depression.

The results of these investigations also indicated that sorghum residues, under favorable conditions, will not decrease crop yields on fertile soils when applied in amounts not exceeding 2 tons per acre, but will actually help to increase yields over those of untreated soils. The increased yields from sorghum residues may be less than from corn or other types of residues, although this is not always the case. When excessively large amounts of organic matter with a wide N-C ratio are incorporated with the soil, depressing effects on crop growth become evident. It is possible that part of the decreased yields of crops following sorghums may be partially explained on the basis of readily decomposable materials in the residues, but such a theory will not satisfactorily explain the large depressions in crop yields reported by some investigators.

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AGRONOMIC AFFAIRS

MEETING OF WESTERN SECTION OF SOCIETY

The fifteenth annual meeting of the Western Section of the Society was held at Logan and Nephi, Utah, July 9 to 11, inclusive. Representatives were present from Utah, Idaho, Oregon, Washington, Colorado, Wyoming, Kansas, California, New Mexico, Greece, Australia, and from the U. S. Department of Agriculture. The following program of technical papers was presented:

Logan, July 9

Decomposition Studies of Alfalfa Tops and Roots after Different Periods of Incubation, T. L. Martin, Brigham Young Univ., Provo, Utah.

Chemical Nature of Peat Deposits, K. R. Stevens, Utah State Agr. Colleg, Logan, Utah.

Carbon and Nitrogen Relationships in Washington Soils, R. E. Bell, College of Agr., Moscow, Idaho.

Range Utilization and Erosion Studies, Geo. Stewart, U. S. Forest Service, Ogden, Utah.

A Study of Hybrids in Various Wheat Variety Crosses, D. C. Tingey, Utah State Agr. College, Logan, Utah.

Weed Experiments in Idaho, H. W. Hulbert, College of Agr., Moscow, Idaho.

Observations at the Second International Congress of Soil Science, U. S. S. R., July–August, 1930, D. W. Pitman, Utah State Agr. College, Logan, Utah.

Utah Farm Villages, P. V. Cardon, Utah Agr. Exp. Sta., Logan, Utah.

New Types of Wheat-rye Hybrids and their Possible Uses, V. H. Florell, U. S. Dept. Agr., Moscow, Idaho.

Nephi, July 11

Tillage Practices in Wheat Growing on the Dry-lands of the Western United States, D. E. Stephens, U. S. Dept. Agr., Moro, Oregon.

Straw-breaking Studies on the Registered Improved and Other Oat Varieties at the Aberdeen Station, Aberdeen, Idaho, L. L. Davis and T. R. Stanton, U. S. Dept. Agr., Aberdeen, Idaho.

Artificial Refrigeration as a Means of Determining the Resistance of Certain Spring Wheats to Frost, J. F. Martin, U. S. Dept. Agr., Moro, Oregon.

Date of Seeding Experiments with Winter Wheat at the Moccasin Station, B. B. Bayles, U. S. Dept. Agr., Mocassin, Montana.

Root Studies of Wheat Varieties, D. E. Stephens, U. S. Dept. Agr., Moro, Oregon.

Probable Error in Relation to Agronomic Experiments, F. V. Owen, U. S. Dept. Agr., Salt Lake City, Utah.

Progress Report on Methods for Estimating Available Phosphorus in Calcerous Soils, R. D. Hockensmith and Alvin Kezer, Ft. Collins, Colo.

Inheritance in Barley, D. W. Robertson, G. W. Deming, and Dwight Koonce, Ft. Collins, Colo.

On the afternoon of July 9, the cereal nursery and agronomic experiments of the Utah Experiment Station were visited; and on July 10, the group toured from Logan to Nephi, a distance of 175 miles. Enroute the Davis County Farm was visited together with the beet experimental plats of the U. S. Dept. of Agriculture Sugar Office at Salt Lake City. The agronomists were the guests of the Brigham Young University at Provo for lunch, and in the late afternoon the Nephi Dry Farm Substation was visited.

The annual dinner was held in Salt Creek Canyon at the Bracken Camp, Saturday evening, July 11, where an address on "The Training of an Agronomist," was delivered by Prof. Alvin Kezer, President of the Section. William Bailey, former president of the National Tax Association, also gave a talk on "Research in Taxation."

An invitation to hold the 1932 meeting at the University of Wyoming was accepted. The following officers were elected for 1932: Aaron F. Bracken of the Utah Experiment Station, *President;* D. E. Stephens, Moro, Oregon, *Vice-president;* and Glenn Hartmen, University of Wyoming, *Secretary*.

THE CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARD

The Chilean Nitrate of Soda Educational Bureau has again made provision for the Chilean Nitrate of Soda Nitrogen Research Award. These awards are designed to foster research on the rôle of nitrogen in economic crop production. Any research worker in the United States or Canada is eligible. In selecting candidates for the award attention is given both to the merits of research already accomplished and to the promise for future work.

The award is administered by the Nitrogen Research Award Committee of the American Society of Agronomy. The amount of the award is decided by the committee in each individual case.

Anyone wishing to call the attention of the committee to their own work or that of any other worker should communicate before November 1st with the Chairman of the Committee, Dr. Richard Bradfield, Dept. of Soils, Ohio State University, Columbus, Ohio. The award will be made at the annual meeting of the American Society of Agronomy in Chicago, November 19 and 20.

ORCHARD SOIL CONFERENCE

As referee for horticulture for the directors of the north-eastern states experiment stations, Dr. U. P. Hedrick, Director of the New York State Agricultural Experiment Station, called a conference at Geneva for September 18 of horticultural workers from the northeastern states interested in orchard soil nutrition problems.

Although the conference was devoted chiefly to informal discussions, the following papers were presented: Some Orchard Soil Problems at the Geneva Station, R. C. Collison, New York State Experiment Station; Orchard Soil Fertility Work at the Massachusetts Station, J. K. Shaw, Massachusetts Agricultural Experiment

Station; Report of a Preliminary Study of the Nutrient Requirements of Red Raspberries, A. E. Stene, Rhode Island Agricultural Experiment Station; Orchard Soil Survey in New York, A. J. Heinicke, New York State College of Agriculture; Organic Matter in Orchard Soil Fertility Experiments, R. D. Anthony, Pennsylvania State College; and the Lay-out and Interpretation of Orchard Fertility Experiments, J. D. Harlan, New York State Experiment Station.

NEWS ITEMS

DR. A. J. PIETERS, for the past several years acting in charge of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, has been named head of that Division.

THE STANDARDIZATION of present wheat varieties and the development of a program for the introduction of new varieties formed the subject for discussion at a meeting held recently by the University of Idaho department of agronomy in cooperation with farmers and millers. Idaho millers have promised the experiment station assistance in the determination of milling and baking quality in new wheats ready for distribution. This will be determined by growing a sufficiently large, controlled acreage of the new variety so that commercial milling and baking tests may be made by the trade. It is expected that this plan will prevent the dissemination of many varieties with poor commercial milling qualities but which are outstanding in yield and other important characteristics. It is believed that this movement is the first of its kind in the United States.

G. R. MCDOLE, formerly Assistant Professor of Agronomy and Soil Technologist at the Idaho Experiment Station, has been appointed Soil Specialist in the Extension Division of the Idaho College of Agriculture. R. E. Bell, formerly Instructor in Soils at the State College of Washington, has been appointed to fill Mr. McDole's position in the Idaho Experiment Station and College.

R. S. BRISTOL, Extension Agronomist, Idaho Agricultural College, has resigned to become Associate Extension Agronomist, U. S. Indian Service, with headquarters at Salt Lake City, Utah. H. L. Spence, formerly Assistant Extension Agronomist, has been advanced to the position vacated by Mr. Bristol.

PROF. W. H. STEVENSON has resigned as head of the Department of Farm Crops and Soils, Iowa State College, and head of the Soils Section of the Iowa Experiment Station, because of ill health. He will continue as part-time professor of soils and vice-director of the Experiment Station. Dr. P. E. Brown has been appointed acting head of the Department.

JOURNAL

OF THE

American Society of Agronomy

VOL. 23 | NOVEMBER, 1931 | NO. 11

THE MOISTURE CONTENT OF FORAGE AT DIFFERENT TIMES IN THE DAY[1]

C. J. WILLARD[2]

There is a rather common opinion that uncut forage has a much lower moisture content during the hot part of the day than in the early morning just after the dew has gone off. The most definite statement to this effect that the writer has seen in agronomic literature is that by Metzger, *et al.*,[3] who recommend very strongly that soybeans should be cut in the hot part of the day because of this difference. Vinall and McKee[4] report preliminary investigations of the question, and do not find important differences at different times of the day. Kiesselbach and Anderson[5] report three days' observations on alfalfa at hourly intervals, in which were recorded a maximum difference of 4.4% in moisture content on any one day, and an average difference of 2.7% in moisture content at 8 a.m. and 5 p.m.

The writer has conducted experiments on this question from time to time for several years. Representative samples of forage, about 1 kilo green weight, have been harvested, placed in cheesecloth sacks, weighed green, then dried in an oven and weighed dry. The oven did not reduce the forage to the moisture-free state, but did very uniformly reduce it to about 2% moisture. The "dry matter" of the tables is this oven-dry material.

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication March 26, 1931.

[2]Associate in Agronomy, Ohio Agricultural Experiment Station, and Professor of Farm Crops, Ohio State University, Columbus, Ohio.

[3]METZGER, J. E., HOLMES, M. G., and BIERMAN, HARLOW. Soybeans. Md. Agr. Exp. Sta. Bul. 277. 1925.

[4]VINALL, H. N., and MCKEE, ROLAND. Moisture content and shrinkage of forage. U. S. D. A. Bul. 353. 1916.

[5]KIESSELBACH, T. A., and ANDERSON, ARTHUR. Alfalfa investigations. Nebr. Agr. Exp. Sta. Res. Bul. 36. 1926.

The first experiment was conducted on June 20, 1924, a very favorable day for producing differences in moisture content if they should exist. From three to five samples were taken of each forage at each time of harvesting. There was a heavy dew at 7 a.m. which was left on the forage in harvesting as far as possible. This dew had gone off by 10 o'clock, permitting a calculation of the percentage of dew on the basis of the green weight of the plants at 10 a.m. The results of this test are given in Table 1.

TABLE 1.—*Dry matter content of forages at different times of day, June 20, 1924.**

Crop	Dry matter in green forage					Dew at 7 A.M. when 10 A.M. = 100, %
	7:30 A.M. %	10 A.M. %	1 P.M. %	4 P.M. %	Average, 10 A.M. 1 and 4 P.M. %	
White sweet clover	14.6	15.4	16.3	15.5	15.7	5.5
Yellow sweet clover	15.7	18.2	18.6	18.8	18.5	15.9
Alfalfa	18.7	20.4	20.9	19.3	20.2	9.1
Alsike clover	11.6	13.5	14.4	12.5	13.5	16.4
Average	15.2	16.9	17.6	16.5	17.0	11.7

*Maximum temperature 93°F.

June of the following year, 1925, was extremely dry, and the forages, which were obviously suffering from drought, almost wilting, seemed favorable for further observations. Samples were taken just after the dew had gone off in the morning, and from 3 to 4 o'clock in the afternoon. The percentages of dry matter in the different forages at these two times are given in Table 2.

TABLE 2.—*Dry matter content of forages at different times of day, 1925.*

Crop and date	Dry matter in green forage		Maximum temperature, °F,
	A.M. %	P.M. %	
June 10, white sweet clover	22.5	23.4	82
June 15–16, white sweet clover	26.6	27.9	91
Yellow sweet clover	27.9	31.3	—
Alfalfa (1st cutting)	33.4	35.7	—
Alfalfa (2nd cutting)	23.6	24.3	—
Alsike clover	32.5	35.5	—
Red clover	25.8	28.2	—
June 22, white sweet clover	27.0	28.6	88
July 3, white sweet clover	27.2	29.4	91
Average	27.4	29.4	—

In 1928, samples of second-cutting alfalfa were taken at 7 and 10 a.m. and at 1 and 4 p.m. of each day from July 6 to August 20.

The data secured are given in Table 3. Some difficulty was experienced with the oven at times during this year, which possibly caused some discrepancies in the data. As in 1924, the dew was left on the 7 a.m. harvests. It had always gone off by 10 a.m., and the percentage of dew at 7 a.m. with the green weight at 10 a.m. as a base was calculated and is reported.

TABLE 3.—*Dry matter in alfalfa at different times of day, 1928.**

Date	Dry matter in green forage					Dew at 7 A.M. when 10 A.M. = 100, %	Maximum temperature, °F
	7 A.M. %	10 A.M. %	1 P.M. %	4 P.M. %	Average, 10 A.M., 1 and 4 P.M. %		
July 6	—	—	—	19.5	19.5	—	84
July 7	13.9	18.1	19.5	21.5	19.7	30.2	90
July 10	15.7	20.7	21.1	20.3	20.7	31.8	86
July 11	18.0	20.0	21.6	21.8	21.1	11.1	89
July 12	20.0	20.7	22.1	22.9	21.9	3.5	82
July 14	19.5	21.5	23.0	21.6	22.0	10.3	75
July 16	20.0	—	21.6	23.4	22.5	—	86
July 17	19.0	23.0	23.8	23.8	23.5	21.1	88
July 18	17.9	22.7	24.5	23.8	23.7	28.5	90
July 19	21.7	23.3	24.9	24.1	24.1	7.4	91
July 23	19.2	24.6	25.7	27.4	25.9	28.1	82
July 24	20.1	24.6	26.2	26.7	25.8	22.4	84
July 25	21.0	26.0	27.3	26.3	26.5	23.8	85
July 26	21.8	26.6	27.1	28.4	27.4	22.0	87
July 27	—	27.3	26.5	—	26.9	—	86
Average, July 7–26	19.0	22.6	23.9	24.0	—	18.9	—
Changed to Another Field, Cut Somewhat Later							
Aug. 8	—	—	—	27.5	27.5	—	90
Aug. 9	22.8	27.4	27.1	27.4	27.3	20.2	92
Aug. 10	24.2	29.2	28.1	28.0	28.4	20.7	87
Aug. 11	26.2	27.8	28.5	28.3	28.2	6.1	80
Aug. 13	24.2	28.9	29.4	29.7	29.3	19.4	80
Aug. 14	26.3	30.3	29.6	30.0	30.0	15.2	86
Aug. 15	24.7	29.2	30.1	30.3	29.9	18.2	86
Aug. 16	29.8	29.8	30.8	31.2	30.6	0.0	79
Aug. 17	28.9	30.3	31.2	33.6	31.7	4.8	90
Aug. 18	26.1	30.1	30.3	30.9	30.4	15.3	78
Aug. 20	26.8	31.4	33.1	31.5	32.0	17.2	88
Average, Aug. 9–20	26.0	29.4	29.8	30.1	—	13.1	—

*Second cutting; previous cutting, June 12.

In 1929 a series was carried out on exactly the same plan with second-cutting red clover which was just coming into bloom at the

time the first harvests were made and was unusually fine hay, about 18 inches in height. This red clover was in full bloom about July 23 and was harvested for seed September 3. A series was also run on second-cutting alfalfa which was in bud on July 13 and nearly in full bloom July 23. Later in the season two varieties of soybeans were harvested in the same way, Manchu from August 5 to August 31, and Peking from September 4 to September 27. The Manchu soybeans were in full bloom when the test started. On August 12 there were numerous pods 1 to 1¼ inches long, but no beans in the pods. By the 19th beans were perceptible in the larger pods. On the 26th the largest beans were one-half grown or more. The Peking soybeans were at the bloom stage when the test started. They set seed very poorly, and the hay did not change materially in appearance

TABLE 4.—*Dry matter in alfalfa at different times of day, 1929.**

Date	Dry matter in green forage					Dew at 7 A.M. when 10 A.M. = 100, %	Maximum temperature, °F
	7 A.M. %	10 A.M. %	1 P.M. %	4 P.M. %	Average 10 A.M. 1 and 4 P.M. %		
July 6	17.5	19.0†	18.5	21.1	19.5	8.6	86
July 9	19.7	20.5	21.7	21.6	21.3	4.0	86
July 10	16.9	—	22.3	22.0	—	—	80
July 11	20.9	21.3	22.4	22.1	21.9	1.9	87
July 12	18.6	21.1	19.9	22.3	21.1	13.4	87
July 13	18.4	19.9	18.7†	—	—	8.1	86
July 15	20.9	22.2	22.6	21.4	22.1	6.2	78
July 16	19.9	21.8	21.0	22.7	21.8	9.5	84
July 17	17.2	22.8	23.9	23.1	23.3	32.5	85
July 18	17.5	21.6	23.9	24.4	23.3	23.4	86
July 19	21.2	22.2	25.3	25.3	24.3	4.7	71
July 20	23.3	22.7	22.1	24.9	23.2	—	74
July 22	20.6	24.4	25.0	27.4	25.6	18.4	85
July 23	—	23.5	24.0	25.0	24.2	—	89
July 24	22.5	23.3	24.3	24.5	24.0	3.6	91
July 25	—	27.4	24.9	26.4	26.2	—	84
July 26	21.6	24.9	28.2	25.0	26.0	15.3	89
July 29	—	—	26.8	27.2	27.0	—	85
July 30	20.0	25.3	26.9	26.2	26.1	26.5	89
July 31	20.8	25.3	27.6	28.4	27.1	21.6	90
Aug. 1	23.6†	26.5	27.0	26.6	26.7	12.3	83
Aug. 2	25.1	26.8	26.2	26.9	26.6	6.8	74
Aug. 5	22.8	27.8	—	—	—	21.9	73
Av. July 6–Aug. 2	20.6	23.0	23.9	24.3	—	11.6	—

*Second cutting; previous cutting, June 10.
†One sample.

during the test. The data for these tests are given in Tables 4, 5, and 6. All of the data for 1928 and 1929 are averages of duplicate samples, except where noted. The hour of day is approximate. The breaks in the records are for various reasons—Sundays, rain, and samples not taken or discarded.

TABLE 5.—*Dry matter in red clover at different times of day, 1929.**

Date	Dry matter in green forage					Dew at 7 A.M. when 10 A.M. = 100, %	Maximum temperature, °F
	7 A.M. %	10 A.M. %	1 P.M. %	4 P.M. %	Average, 10 A.M. 1 and 4 P.M. %		
July 13	13.2	14.6	—	15.7†	15.1	10.6	86
July 15	13.8	15.1	17.0	16.2	16.1	9.4	78
July 16	14.5	16.1	16.6	17.6	16.8	11.0	84
July 17	13.6	16.2	16.4	16.7	16.4	19.1	85
July 18	13.2	17.1	18.3	17.0	17.5	29.5	86
July 19	16.2	16.5	16.4	18.4	17.1	1.8	71
July 20	16.3	16.7	18.9	18.8	18.1	2.4	74
July 22	16.0	17.7	16.4	18.2	17.4	10.6	85
July 23	16.2	16.7	17.9	18.8	17.8	3.1	89
July 24	16.6	18.3	19.4	18.8	18.8	10.2	91
July 25	—	19.4	18.7	19.9	19.3	—	84
July 26	17.5	20.7	20.0	19.6	20.1	18.2	89
July 29	—	—	20.9	22.8	21.8	—	85
July 30	17.3	22.1	23.0	22.9	22.7	27.7	89
July 31	18.6	22.1	24.9	25.4	24.1	18.8	90
Aug. 1	21.6	24.5	26.5	25.8†	25.6	13.4	83
Aug. 2	21.9	24.8	25.1†	26.6	25.5	13.2	74
Aug. 5	22.0†	23.0	23.9	26.1	24.3	4.5	73
Aug. 6	24.2	24.1	24.2	24.3	24.2	—	77
Aug. 7	23.1	24.8	27.3	25.8	26.0	7.3	78
Aug. 8	22.2	24.6	24.9	24.4	24.6	10.8	82
Aug. 9	22.7	24.8	24.5	24.4	24.6	9.2	85
Aug. 10	21.4	27.1	26.8	26.8	26.9	26.6	88
Aug. 12	27.7	28.3	27.8	28.4	28.2	2.1	83
Aug. 13	25.5	27.2†	28.8	28.8	28.3	6.6	87
Aug. 14	25.3	—	—	—	—	—	73
Aug. 15	—	27.3	26.5	28.7	27.5	—	67
Aug. 16	22.3	30.3	28.1	28.5	29.0	35.8	76
Aug. 17	25.6	32.0	31.0	29.3	30.8	25.0	85
			Averages				
July 15–20	14.6	16.3	17.3	17.4	—	11.6	—
July 22–Aug. 2	18.2	20.9	21.6	22.0	—	14.8	—
Aug. 5–10	22.6	24.7	25.3	25.3	—	9.3	—
Aug. 12–17	25.3	29.4	28.9	28.8	—	16.2	—
July 15–Aug. 17	19.6	22.1	22.7	22.8	—	12.8	—

*Second cutting; previous cutting, June 15.
†One sample.

TABLE 6.—*Dry matter in soybeans at different times of day, 1929.*

Date	Dry matter in green forage					Dew at 7 A.M. when 10 A.M. = 100, %	Maximum temperature, °F
	7 A.M. %	10 A.M. %	1 P.M. %	4 P.M. %	Average, 10 A.M. 1 and 4 P.M. %		
			Manchu				
Aug 5	17.6	17.9	18.9	17.8	18.2	1.7	73
Aug. 6	15.9	16.8	18.5	19.2	18.2	5.7	77
Aug. 7	16.4	17.7	18.8	18.3	18.3	7.9	78
Aug. 8	15.0	17.2	17.5	17.7	17.5	8.3	82
Aug. 9	15.7	17.0	18.1	20.2	18.4	8.3	85
Aug. 10	15.7	17.3	18.2	18.3	17.9	8.9	88
Aug. 12	15.5	17.8	17.7	18.9	18.1	14.8	83
Aug. 13	16.9	19.0	21.0	19.9	20.0	12.4	87
Aug. 14	18.0	17.7	—	—	—	—	73
Aug. 15	—	18.4	18.9	18.9	18.7	—	67
Aug. 16	15.9	18.6	19.0	18.8	18.8	17.0	76
Aug. 17	17.0	19.3	19.8	19.0	19.4	13.5	85
Aug. 19	—	20.9	20.4	20.5	20.6	—	75
Aug. 20	18.3	19.6	20.8	20.2	20.2	7.1	74
Aug. 21	17.3	19.4	19.4	20.3	19.7	12.1	84
Aug. 22	17.3	—	—	21.6	—	—	83
Aug. 26	—	20.0	19.5	20.5	20.0	—	86
Aug. 27	19.8	19.9	20.5	20.7	20.4	0.5	75
Aug. 28	17.1	21.0	20.3	19.1	20.1	22.8	69
Aug. 29	19.5	18.6	21.4	19.1	19.7	—	71
Aug. 30	18.3	19.6	19.8	20.9	20.1	7.1	74
Aug. 31	17.6	21.1	24.4	—	22.8	19.9	82
			Peking				
Sept. 4	19.6	20.8	22.9	22.4	22.0	6.1	88
Sept. 5	17.2	19.0	20.2	20.9	20.0	10.5	88
Sept. 6	—	—	19.3	20.0	19.7	—	83
Sept. 7	17.3	18.7	—	—	18.7	8.1	80
Sept. 10	19.1	18.9	20.9	19.0	19.6	—	72
Sept. 11	15.7	19.6	18.4	18.9	19.0	24.8	68
Sept. 12	16.7	18.7	19.1	18.9	18.9	12.0	78
Sept. 16	15.7	19.1	20.4	19.2	19.6	21.6	75
Sept. 17	17.5	18.6	19.7	20.3	19.5	6.3	70
Sept. 18	17.3	19.0	19.8	21.3	20.0	9.8	57
Sept. 19	17.1	22.1	20.9	22.0	21.7	29.2	58
Sept. 20	19.7	21.0	20.3	22.1	21.1	6.6	63
Sept. 21	20.4	20.6	21.7	21.9	21.4	1.0	67
Sept. 23	18.8	22.4	22.0	21.1	21.8	19.1	77
Sept. 24	17.6	21.1	21.5	23.3	22.0	19.9	79
Sept. 25	20.8	21.3	20.5	20.1	20.6	2.4	74
Sept. 27	—	—	20.6	19.3	20.0	—	82
			Averages				
Aug. 5–10	16.0	17.3	18.3	18.6	—	8.1	—
Aug. 12–21	16.8	19.0	19.6	19.5	—	13.1	—
Aug. 26–30	18.7	19.8	20.5	20.0	—	5.9	—
Aug. 5–30	17.0	18.5	19.4	19.3	—	8.8	—
Sept. 4–25	18.1	20.2	20.6	20.8	—	11.6	—

SUMMARY AND CONCLUSIONS

Studies of the percentage of dry matter in forage at different times of the day have been made on alfalfa, soybeans, red clover, sweet clover, and alsike clover over a series of years and for continuous periods in the development of the forages, involving several hundred observations.

After the dew is off, the range in the percentage of dry matter in the green forage was almost never greater than 3%, and the average range for periods of a week or more was always less than 2%. Since in curing hay it requires but a comparatively short time to evaporate 1 to 3% of moisture, it seems clear that there is not sufficient change in the moisture content of forage after the dew is off to be a practical factor in hay-making.

The amount of dew on the forage at 7 a.m. ranged up to 1/5 or even ¼ of the green weight of the forage in some especially heavy dews.

The data showed a gradual and fairly uniform increase in the percentage of dry matter in the green forage as the forages became more mature. This was not so noticeable in soybeans as in red clover and alfalfa.

BREEDING RUST-RESISTANT VARIETIES OF SPRING WHEAT[1]

C. H. GOULDEN and K. W. NEATBY[2]

In the breeding of varieties of wheat resistant to stem rust, definite progress has been made. This progress may be directly attributed to two important advances in our knowledge of the problem. In the first place, as demonstrated originally at the Minnesota Agricultural Experiment Station (7),[3] the rust resistance of durum and emmer varieties can be transferred successfully to varieties of *Triticum vulgare*. The same process has been repeated by McFadden (8), with an Emmer x Marquis cross, and at the Dominion Rust Research Laboratory (4) with a Pentad x Marquis cross.

[1]Contribution from the Cereal Division, Dominion Department of Agriculture, Ottawa, Canada. Also presented as part of a symposium on "Plant Breeding" at the annual meeting of the Society held in Washington, D. C., November 20, 1930. Received for publication April 2, 1931.

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[3]Reference by number is to "Literature Cited," p. 870.

The second step in advance was the discovery of the independent inheritance of mature plant and seedling resistance. The results of investigations conducted at the University of Minnesota by Hayes and his associates (6, 7) demonstrated that seedling reactions determined in the greenhouse were not a reliable criterion of field reactions. Certain hybrid lines were found to exhibit considerable resistance under field conditions in spite of being completely susceptible to several physiologic forms of *Puccinia graminis tritici* as determined by seedling reactions in the greenhouse.

In a study of the cross H-44-24 x Marquis, Goulden, *et al.* (2), found that the high field resistance of H-44-24 was inherited quite independently of the seedling reaction in the greenhouse. As a result of these investigations, mature plant resistance came to be regarded as a distinct entity; more emphasis was given to it in breeding work and particular attention given to its significance in relation to physiologic specialization in *Puccinia graminis tritici*. The results obtained to date indicate that the mature plant resistance of H-44-24 and Hope is equally effective, or nearly so, with all known physiologic forms. If such is actually the case, all physiologic forms may be regarded as one from a breeding standpoint.

In this paper a brief account is given of the behaviour of certain varieties with respect to mature plant and seedling resistance, of the mode of inheritance of mature plant resistance in certain crosses, and of some of the practical results obtained. In discussing the practical results emphasis is placed on the various tests applied in order to obtain complete information on the behaviour of the new rust-resistant strains.

BEHAVIOR OF VARIETIES

In a recent study (5), the reactions of 14 varieties of wheat in the seedling and mature plant stages to 16 physiologic forms of stem rust were obtained. The charts in Fig. 1, for the varieties Marquis, Quality, H-44-24, and Acme, illustrate two extremes. The rust classes refer to the type of pustule, class 2 representing high resistance (0;) and class 24 complete susceptibility (4++). For Marquis and Quality there is a good agreement between the seedling and mature plant reactions, but for H-44-24 and Acme there is an almost complete lack of agreement. Acme, which is susceptible to all of the 16 forms in the seedling stage, is resistant to all of these forms in the mature stage. H-44-24 is characterized by a mature plant reaction similar to that of Acme, but is susceptible to at least seven of the physiologic forms in the seedling stage and resistant to the remainder.

Two other varieties, Hope and Pentad, gave results very similar to those for H-44-24 and Acme, while the varieties Reward, Kota, and Marquillo gave only moderate indications of mature plant resistance.

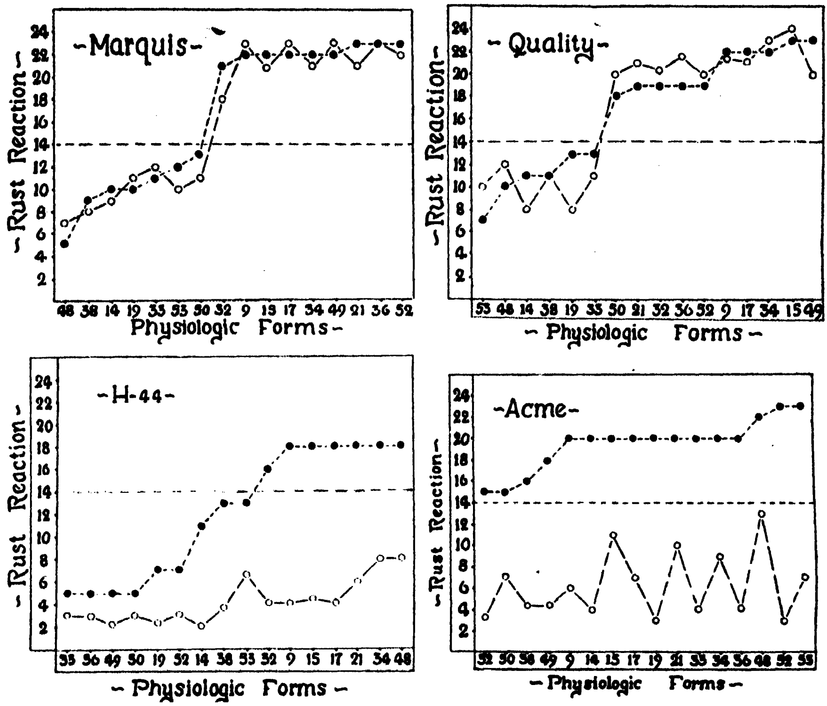

FIG. 1.—The relation between the seedling reaction (solid dots) and the mature plant reaction (circles) in the varieties Marquis, Quality, H-44-24, and Acme.

INHERITANCE OF MATURE PLANT RESISTANCE

It was first demonstrated definitely in 1928 (2) that mature plant resistance could be completely independent of seedling resistance in inheritance. Table 1 gives the results in brief which were presented at that time for the cross H-44-24 x Marquis.

TABLE 1.—*Segregation in the field for rust reaction of two groups of F_3 families, one group resistant to some forms in the seedling stage and the other group susceptible.*

Seedling reaction	Field reaction			
	Homozygous resistant	Segregating	Homozygous susceptible	Totals
Resistant to forms 36, 21..	8	18	10	36
Susceptible to forms 36, 21.	6	18	8	32
Totals.............	14	36	18	68

$X^2 = 0.275$ P = .90 to .80

It is obvious from Table 1 that in each group there is a 1:2:1 segregation of resistant, segregating, and susceptible families in each seedling reaction group. More recent seedling tests have shown that the group referred to here as resistant in the seedling stage to forms 36 and 21 possessed practically all of the seedling resistance of the H-44-24 parent. In the field an artificial epidemic was created in which about 30 forms, including 36 and 21, were used so that the results cannot be attributed to the absence of these forms.

The above results indicate that in this cross the inheritance of the mature plant resistance of H-44-24 is governed by a single pair of factors. This has been borne out by later studies, but in some other crosses the inheritance is more complicated. A report was given in 1930 (9) of the results from eight crosses in which one of the parents was either H-44-24 or the sister strain Hope. One of the most striking results was the different behaviour of Hope as compared to H-44-24. The Hope resistance is apparently governed by at least two genetic factors. In crosses involving Reward good evidence was obtained of an inhibitor in this variety to the mature plant resistance of Hope and H-44-24. In the same 1930 report results were given for the inheritance of rust resistance in crosses between Marquillo and susceptible varieties. In these crosses only a very small proportion of the progeny showed the resistance of the Marquillo parent. Table 2 illustrates this point, and it is evident from these results that the high resistance of Hope and H-44-24 is inherited in a much more simple manner than is the moderate resistance of Marquillo.

TABLE 2.—*Frequencies in the various rust infection classes of the F_2 generation of several different crosses.*

Cross	Year	R	SR	MS	S	Probable number of factors concerned
Marquis x H-44-24	1928	966	—	—	314	1
H-44-24 x (Marquis-Kanred B_{2}-5)	1929	182	416	—	233	1
H-44-24 x Reward	1928	264	—	—	915	2
Marquis x Hope	1929	186	661	—	502	2
Webster x H-44-24	1929	112	80	203	270	2
Hope x Reward	1929	111	232	—	1,181	3
Double Cross x H-44-24	1929	689	519	—	339	3
Marquillo x H-44-24	1928	229	147	—	51	3+
Marquillo x (Marquis-Kanred B_{2-5})	1927	4	33	—	775	3+
Marquillo x (Marquis-Kanred $_{2-5}$)	1928	1	18	109	857	3+
Marquillo x Reward	1927	1	90	—	1,507	many
Garnet x Marquillo	1927	1	81	—	4,929	many

Mention has already been made of a Pentad x Marquis cross which resulted in the production of strains of the *vulgare* type possessing the rust resistance of the Pentad parent. This was also reported in 1929 (4). Some F_3 families from this cross segregated in a 3:1 ratio of resistant to susceptible plants, as shown in Table 3.

TABLE 3.—*Segregation in the field for resistance and susceptibility of two F_3 lines of Marquis x Pentad.*

Line No.	Number of plants			X^2	P
	Resistant	Susceptible	Total		
C-25-F_3-2	125	39	164	0.1301	.70
C-25-F_3-8	106	25	131	2.4453	.10
Total	231	64	295	2.5754	.30

Data on the relation between seedling and mature plant resistance were obtained from this material in a study of the seedling reactions of a random sample of 12 F_4 families. These were tested to forms 48, 14, 52, and 36. The results are given in Table 4.

TABLE 4.—*Seedling reactions to forms 48, 14, 52, and 36, of 12 F_5 lines of Pentad x Marquis which are highly resistant in the field.*

Line No.	Reactions to physiologic forms			
	48	14	52	36
1322	1+	1+	4+	4
1324	1+	1—	4+	4
1326	2—	1	4+	4
1335	2—	1±	4+	4
1342	1+	1+	4+	3+
1344	2	2—	4+	3+
1347	1	1	4	4
1350	1	2—	4	3+
1352	2—	1	4—	4
1354	1+	1	4	3+
1355	2—	1	4	3+
1358	1	1	4	3+

The reactions obtained are practically identical with the reaction of Marquis to these four forms and establishes beyond doubt the independence in inheritance of seedling resistance and the mature plant resistance characteristic of Pentad.

PRACTICAL RESULTS

Under this heading tests are described that have been conducted on groups of strains possessing a high degree of mature plant resistance. These groups came from three crosses, *viz.*, H-44-24 x Marquis, H-44-24 x Reward, and Pentad x Marquis. For convenience the discussion is divided under the sub-headings of disease resistance, yield, and quality.

DISEASE RESISTANCE

A group of 86 rust-resistant strains from the cross H-44-24 x Marquis was first tested in rod rows in 1928. During that season an epidemic of black chaff occurred in the nursery, and since H-44-24 is fairly susceptible, the disease was found in varying degrees among the strains under test. It was decided that a study of the effect of susceptibility to black chaff and other characteristics on yield would be quite valuable, so correlation coefficients were calculated for all possible combinations of the following characters: Y = yield, B = black chaff, E = earliness (days from seeding to heading), S = strength of straw, H = height, and W = weight of 500 kernels. The total and partial coefficients are given in Table 5, which is reproduced in part from the complete report (3) published in 1929.

TABLE 5.—*Correlation coefficients for characters of H-44-24 x Marquis strains.*

Characters	Zero order coefficients	t	Characters	Partial coefficients	t
YE	—.3790	3.66	YE.BSHW	—.4530	4.42
YH	.6147	6.97	YH.BESW	.4996	5.03
YB	—.4991	5.15	YB.ESHW	—.2562	2.31
YS	—.2477	2.99	YS.BEHW	.0813	—
YW	.4991	5.15	YW.BESH	.2632	2.38

Multiple correlation $R_{Y.BESHW} = .7853$

The significance of the correlation coefficients is given by the corresponding values of t. When t is 2.0 or greater the coefficients are considered significant. The method of calculating t is that given by Fisher (1). A small, but significant, correlation was obtained between yield and percentage of black chaff. In a group of Marquillo strains tested the same season a heavier infection of black chaff occurred and the partial correlation $R_{YB.ESHW}$ was — .4556.

During the same season the awned and awnless strains from H-44-24 x Marquis were compared for black chaff infection and yield. These results are given in Table 6.

TABLE 6.—*Contingency tables for relations between awning, black chaff, and yield in a group of lines from an H-44-24 x Marquis cross.*

	Black chaff, percentage basis			Total	Mean*	X^2	P
	6–15	16–25	26–40				
Awned	9	24	4	37	18.44	6.54	.039
Awnless	3	37	10	50	21.90		
	Average yield in grams						
	151–200	201–250	251–325				
Awned	6	7	21	34	245.6	15.87	.0004
Awnless	18	21	9	48	215.6		

*Means calculated from finer groupings.

The awned strains were less heavily infected with black chaff than the awnless ones and gave heavier yields. Both of these results are significant. The difference in black chaff infection may have caused the difference in yield, but the latter result is a very definite one and it seems reasonable that the heavier yields may be due in part to the physiologic effect of the awns.

In 1930, a group of 25 H-44-24 x Reward strains were tested for the first time in rod rows. They can be compared in this experiment with another group of 32 Pentad x Marquis strains, also in the rod rows for the first time, and with standard varieties and some smaller groups of resistant strains. For convenience the latter group is referred to here as the standard variety group, although it includes several moderately resistant strains from other crosses. Comparing these groups from the standpoint of black chaff infection, we get the results given in Table 7 in the form of an analysis of variance. This form of analysis is the one suggested by Fisher (1) and serves admirably to sort out the important features of the test.

TABLE 7.—*Black chaff analysis of variance comparing standard varieties with two groups of rust-resistant strains, 1930.*

Variance due to	Sums of squares	Degrees of freedom	Variance or mean square	½ log e	z	5% point
Replicates	78.55	2	——	——	——	—
Between groups	2,208.80	2	1,104.40	3.5036	1.8368	0.5585
Within standard varieties	155.27	19	8.17	——	——	——
Within Pentad x Marquis strains	723.96	31	23.35	——	——	——
Within H-44-24 x Reward strains	5,110.00	24	212.92	2.6805	1.0137	0.2310
Error	4,261.78	152	28.04	1.6668	——	——
Total	12,538.36	230	——	——	——	——

	Mean	Standard error
Standard varieties	0.70	.54
Pentad x Marquis strains	1.98	.61
H-44-24 x Reward strains	8.00	.68

The analysis of variance gives an independent estimate of the variance of the test from each of the components, included, between groups, within standard varieties, and within H-44-24 x Reward strains. These can be compared with the estimate of variance due to soil heterogeneity or the random error in the test. The calculated values of Z and the values of Z at the 5% point given in the last two columns of the table show at a glance the degree of significance which can be attributed to the separate estimates of variance. If the calcu-

lated value of Z exceeds that given for the 5% point, the odds of significance are greater than 20:1. It is obvious from the table that the greater part of the total variance is made up by differences between the groups, and this is reflected in the mean values for the groups given at the foot of the table. These mean values are accompanied by their standard errors and it is evident that the difference between the standard varieties and the Pentad x Marquis strains is hardly significant, while the difference between the H-44-24 x Reward strains and either of the other two groups is well beyond the possibility of chance occurrence. The significance of the variance between groups can therefore be directly attributed to the greater average susceptibility to black chaff of the H-44-24 x Reward strains.

Another point remains to be noted from this table. The variance within the H-44-24 x Reward strains is significant. This indicates that, while a considerable degree of susceptibility exists among the strains, there are real differences among them and that selection would be of value.

Applying a similar analysis to the data for stem rust on the same set of varieties and strains, the results given in Table 8 are obtained.

TABLE 8.—*Stem rust analysis of variance comparing standard varieties with two groups of rust-resistant strains, 1930.*

Variance due to	Sums of squares	Degrees of freedom	Variance or mean square	½ log e	z	5% point
Replicates	114.31	2	57.16*	3.1742	3.0707	0.5585
Between groups	46,167.44	2	23,083.72	6.1748	6.0713	0.5585
Within standard varieties	45,152.85	19	2,376.46	4.9689	4.8654	0.2487
Within Pentad x Marquis strains	22,884.50	31	738.21	4.4534	4.3499	0.2113
Within H-44-24 x Reward strains	3,169.82	24	132.07	3.5930	3.4895	0.2310
Error	18.68	152	0.123	0.1035	——	——
Total	117,507.60	230	——	——	——	——

	Mean	Standard error
Standard varieties	40.20	.035
Pentad x Marquis strains	8.04	.039
H-44-24 x Reward strains	7.89	.044

*Variance figures multiplied by 10 for calculation of log e.

The results here are very marked. Experimental error is very small and the enormous total variance is made up almost entirely of varietal and strain differences. Owing to the small random error, all of the estimates of variance are significant, as shown in the last

two columns of Table 8. The data justify the conclusion that real differences exist among all three groups, although these differences are much less striking, as would be expected in the groups of resistant strains. We may, of course, compare any pair of estimates of the variance by obtaining the corresponding value of Z, which is one-half the difference between their natural logarithms. Such tests show that the differences within the standard varieties are significantly greater than those within the two groups of resistant strains. This is due of course to the former group possessing very susceptible as well as moderately resistant strains.

In 1930, a special test, consisting of triple rod rows replicated 8 times, was planned in order to compare eight strains from a Pentad x Marquis cross and eight strains from an H-44-24 x Marquis cross with the standard varieties Marquis, Garnet, Reward, and H-44-24. The same varieties and strains were repeated in a large general test consisting of triple rod rows replicated 5 times. Thus, there were 13 plats in all of each variety and the results from the two experiments have been combined and analysed for the data on stem rust, as shown in Table 9.

TABLE 9.—*Stem rust analysis of variance for standard varieties compared with two groups of rust-resistant strains, 1930.*

Variance due to	Sums of squares	Degrees of freedom	Variance or mean square	½ log e	5% point
Replicates	105.64	12	——	——	——
Between groups	158,117.48	2	79,058.74	5.6390	0.5552
Within standard varieties	69,651.77	3	23,217.26	5.0240	0.4862
Within Pentad x Marquis strains	330.61	7	47.23	——	——
Within H-44-24 x Marquis strains	138.15	7	19.74	——	——
Error	1,336.64	228	58.62	2.0356	——
Total	229,680.29	259	——	——	——

	Mean	Standard error
Standard varieties	65.2	1.06
Pentad x Marquis strains	4.2	.75
H-44-24 x Marquis strains	2.9	.75

Table 9 brings out two facts very distinctly. The differences between the groups are very marked and also within the standard varieties. As indicated by the means at the foot of the table the differences between the groups are accounted for almost entirely by the greater susceptibility of the standard varieties. The differences between the Pentad x Marquis and H-44-24 x Marquis strains are not significant.

In the standard variety group, the large variance is due to the extreme difference between H-44-24 and the other three varieties which are quite susceptible.

YIELD

Referring again to the preliminary rod row test, applying the analysis of variance to the yield data brings out some very important points. The results are given in Table 10.

TABLE 10.—*Yield analysis of variance comparing standard varieties with two groups of rust-resistant strains, 1930.*

Variance due to	Sums of squares	Degrees of freedom	Variance or mean square	½ log e	z	5% point
Replicates	278.46	2	139.23	2.4681	0.9808	0.5585
Between groups	461.77	2	230.88	2.7210	1.2337	0.5585
Within standard varieties	1,441.89	19	75.89	2.1646	0.6773	0.2487
Within Pentad x Marquis strains	603.45	31	19.47	——	——	——
Within H-44-24 Reward strains	462.76	24	19.28	——	——	——
Error	2,976.27	152	19.58	1.4873	——	——
Total	6,224.60	230	——	——	——	——

	Mean	Standard error
Standard varieties	20 80	57
Pentad x Marquis strains	23.49	.45
H-44-24 x Reward strains	20.50	.51

There is a significant difference between the groups, but the mean values at the foot of the table show that this is entirely due to the higher yielding ability of the Pentad x Marquis strains. The H-44-24 x Reward strains in detailed data contain strains giving much higher yields than some of the susceptible varieties, but taken as a group they give practically the same yield as the heterogeneous group of standard varieties. Within the Pentad x Marquis and the H-44-24 x Reward groups there is no evidence whatever of real differences in yielding ability. At least, if there are such differences, the random error in the test is too great to enable these to be brought out.

Combining the results from the general and special tests, we have the analysis of the yield data given in Table 11.

The results in Table 11 are, in general, very much the same as those in Table 10. Again the significance of the difference between the groups and within the standard varieties will be noted, while within the groups of the resistant strains the differences are small. The differences between the groups as indicated by the mean values are entirely due to the lower yields of the standard varieties as compared to the resistant strains.

TABLE 11.—*Yield analysis of variance for standard varieties compared with two groups of rust-resistant strains, 1930.*

Variance due to	Sums of squares	Degrees of freedom	Variance or mean square	½ log e	z	5% point
Replicates	611.50	12	—	—	—	—
Between groups	3,640.19	2	1,820.10	3.7533	2.1832	0.5552
Within standard varieties	1,247.81	3	415.94	3.0153	1.4452	0.4862
Within Pentad x Marquis strains	290.63	7	41.52	1.8631	0.2930	0.3628
Within H-44-24 x Marquis strains	188.51	7	26.93	1.6466	0.0765	0.3628
Error	5,269.22	228	23.11	1.5701	—	—
Total	11,247.86	259	—	—	—	—

	Mean	Standard error
Standard varieties	13.50	2.00
Pentad x Marquis strains	27.36	1.00
H-44-24 x Marquis strains	27.64	.71

The group of H-44-24 x Marquis strains, for which data are given in Tables 9 and 11, have been tested for 3 years in the rod rows, and the comparable group of Pentad x Marquis strains have been in the same test for 2 years. The yield data are summarized in Table 12. In 1928 there was not sufficient stem rust to affect the yields and in 1929 it had only a very small effect. The data during these 2 years, therefore, give some idea as to the yielding capacity

TABLE 12.—*Yields of standard varieties and two groups of rust-resistant strains 1928 to 1930.*

Variety	Rust laboratory No.	1928	1929	1930*	Average yield
Marquis	96	29.1	23.2	5.7	19.3
Garnet	15	29.3	25.2	9.4	21.3
Reward	79	26.9	21.6	15.5	21.3
H-44-24 x Marquis	586	29.6	28.4	30.3	29.4
H-44-24 x Marquis	590	22.5	25.4	26.6	24.8
H-44-24 x Marquis	592	18.7	26.4	28.9	24.7
H-44-24 x Marquis	594	23.1	24.6	25.6	24.4
H-44-24 x Marquis	595	20.8	26.0	21.8	22.9
H-44-24 x Marquis	609	28.6	23.1	27.3	26.3
H-44-24 x Marquis	614	18.1	26.8	27.0	24.0
H-44-24 x Marquis	615	28.5	27.3	27.1	27.6
Pentad x Marquis	723	—	26.9	24.4	25.6
Pentad x Marquis	724	—	30.5	24.8	27.6
Pentad x Marquis	725	—	26.2	23.7	25.0
Pentad x Marquis	726	—	26.2	26.0	26.1
Pentad x Marquis	727	—	27.8	24.7	26.2
Pentad x Marquis	728	—	25.7	20.6	23.2
Pentad x Marquis	729	—	31.0	31.8	31.4
Pentad x Marquis	730	—	26.7	28.0	27.4

*Yields taken from special eight-replicate test.

of the hybrid strains in years when rust is not prevalent. In 1930 a very severe epidemic of rust occurred and the yields of such varieties as Marquis, Garnet, and Reward were consequently very much reduced. Considering the 3 years—two without rust and one with rust—it is evident that the rust-resistant strains are, in general, a good deal better yielders than the best standard varieties.

QUALITY

Baking quality tests on the rust-resistant strains for which yields are given in Table 12 have been conducted by the milling and baking laboratory of the Cereal Division at the Central Experimental Farm. Two tests have been made on the H-44-24 x Marquis strains and one test on the Pentad x Marquis strains. These data need not be given in detail as in all the tests both groups of strains have been equal in quality to Marquis.

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THE EFFECT OF AMMONIUM SULFATE ON SOIL REACTION[1]

J. W. WHITE[2]

Experimental evidence points conclusively to the fact that ammonium sulfate has a strong tendency toward the development of soil acidity. As the result of the processes of absorption and subsequent nitrification of the ammonium cation the calcium salts of nitric and sulfuric acid are formed, both of which are more soluble in water than the basic lime from which they are derived. The depletion of the basic lime in this manner hastens the development of a permanent measurable acidity.

The extensive experimental use of ammonium sulfate has made possible a quantitative field study of the acidity produced through a period of years. The old field plat experiments of the Pennsylvania Agricultural Experiment Station offer an excellent opportunity for such a study.

PENNSYLVANIA FIELD PLAT EXPERIMENT

This old field plat experiment, established in 1881 on Hagerstown soil of limestone origin, includes 144 plats arranged in four tiers of 36 plats each. The fertilizers are applied to corn and wheat in a 4-year grain rotation of corn, oats, wheat, and hay (mixed clover and timothy). Included in the scheme of plat treatments are three plats of each tier which receive ammonium sulfate in amounts sufficient to furnish 24, 48, and 72 pounds of nitrogen per acre, designated as plats 30, 31, and 32, respectively. These plats also receive a uniform dressing of superphosphate and muriate of potash sufficient to supply 48 pounds of phosphoric acid and 100 pounds of potash (K_2O). No lime was applied during the first 40 years of the experiment to any plats which receive commercial fertilizers. In 1922 and 1923, however, plats of tiers two and four, respectively, were limed. The ammonium sulfate plats of these two tiers each received a uniform application of 5 tons per acre of 20-mesh limestone. Four plats of each tier receive PK fertilizers in amount indicated for the ammonium sulfate plats. These plats in this study, therefore, serve as check or

[1]Contribution from the Department of Agronomy, Pennsylvania Agricultural Experiment Station, State College, Pa. Also read as part of the symposium on "Production, Characteristics, and Use of the Several Carriers of Fertilizer Nitrogen" at the annual meeting of the Society held in Washington, D. C., November 21, 1930. R ceived for publication March 4, 1931.

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control treatments since the increase in yields or acidity of the ammonium sulfate plats over the PK treatments may be attributed to the ammonium sulfate applied.

ACIDITY OF AMMONIUM SULFATE PLATS[3]

In 1910, 1915, and 1921, all plats of the series were sampled and lime requirement determinations were made on each sample. The 1910 study was made by Gardner and Brown (1)[4] who used the original Veitch lime water method (2). The 1915 studies were made by the author who also used the Veitch lime water method (3). The acidity studies on the samples taken in 1921 were made by the author assisted by F. J. Holben. The lime requirement of the plat soils sampled in 1921 is based on a lime requirement method devised by the author and represents a modification of the Jones method standardized against the Veitch method. The details of this new method are given below.

THE AUTHOR'S LIME REQUIREMENT METHOD

Ten grams of 20-mesh air-dried soil are shaken for 30 minutes (at 5-minute intervals) with 200 cc of a N/28 solution of calcium acetate, using a 300-cc stoppered Erlenmeyer flask. At the end of 30 minutes the contents of the flask are shaken and immediately filtered, discarding the first 25 cc of the filtrate. One hundred cc of the clear filtrate are then titrated with N/50 sodium hydroxide, using a slight excess of phenolphthalein indicator and titrating to a permanent rose pink. Subtract 3 cc from the initial burette reading and multiply the remainder by 2. Each cc is equivalent to 474 pounds per acre $CaCO_3$.

An initial burette reading of 3 cc indicates a neutral soil. A reading of less than 3 cc indicates an alkaline soil. The factor 474 was obtained by standardizing the sodium hydroxide solution against several hundred soil samples, the lime requirements of which had previously been determined by the Veitch method. The soil samples used for this purpose were collected as the result of a lime requirement survey of Pennsylvania soils (4) and therefore were representative of all the soil series of the state.

This lime requirement method has many advantages over the two methods from which it is derived and has been found capable of measuring very slight changes in soil reaction as the result of small lime applications not always indicated by pH studies.

The acidity or lime requirement results are based on the average

[3]The yields of all plats before and after liming have been published in Pa. Agr. Exp. Sta. Bul. 264. 1931.

[4]Reference by number is to "Literature Cited," p. 877.

of three tiers of plats (tiers 1, 3, and 4). Since PK is also applied to all ammonium sulfate plats, the lime requirement is expressed as that found in excess of the PK plats 25 and 29. Table 1 shows the lime requirement of the three ammonium sulfate plats based on three different sampling periods. The lime requirement figures represent the pounds of $CaCO_3$ required per acre 2,000,000 pounds of soil.

TABLE 1.—*Lime requirement of the ammonium sulfate plats in excess of the average of the two nearest PK treatments.*

	Plat 30 (24N)	Plat 31 (48N)	Plat 32 (72N)
Lime requirement 1910	1,074	2,433	2,883
Lime requirement 1915	1,372	2,757	3,991
Lime requirement 1921	1,639	3,469	4,181

Many theories have been advanced concerning the action of ammonium sulfate in the formation of soil acidity, as noted by Pierre (5). On the basis of the more recent base exchange theories advanced by Page (6), 2 molecules of dibasic acid are formed for each molecule of ammonium sulfate applied. The three reactions as discussed by Pierre (5) are as follows:

$$(NH_4)_2SO_4 + CaX \longrightarrow CaSO_4 + (NH_4)_2X \quad (1)$$

$$(NH_4)_2X + O_2 \underset{\longrightarrow}{\text{nitrification}} 2\,HNO_3 + H_2X + 2\,H_2O \quad (2)$$

$$2HNO_3 + CaX \longrightarrow Ca(NO_3)_2 + H_2X \quad (3)$$

In the above reactions CaX represents the absorbing complex of the soil in which Ca represents the various exchangeable bases with which the insoluble anions, X, are combined in an exchangeable form. For ease of discussion, it is assumed that X can only combine with one Ca.

On the basis of the above three reactions in which are formed 2 molecules of dibasic acid for each molecule of ammonium sulfate applied, 1 pound of ammonium sulfate would react with 1.515 pounds of $CaCO_3$, or in the proportion of 132:200, as follows:

$$2H_2X + 2CaCO_3 \longrightarrow 2CaX + 2CO_2 + 2H_2O$$

It is of interest to compare the theoretical lime requirement on the basis of the above reactions with the actual requirement found at three periods of the plat experiment. Since the amounts of ammonium sulfate applied, based on pure material, are known, the theoretical lime requirement is obtained by multiplying the pounds of ammonium sulfate by 1.515. Table 2 shows such a comparison.

A study of the data in the above table shows that the theoretical lime requirement is approximately twice that actually found. The field data therefore fail to correlate with the theoretical reactions presented.

TABLE 2.—*Comparison of theoretical lime requirement (pounds of ammonium sulfate multiplied by 1.515) with that actually found at three periods of the experiment.*

	Plat 30	Plat 31	Plat 32
Theoretical lime requirement 1910	2,398	4,796	7,194
Actual lime requirement 1910	1,074	2,433	2,883
Theoretical lime requirement 1915	2,912	5,924	8,736
Actual lime requirement 1915	1,372	2,757	3,991
Theoretical lime requirement 1921	3,428	6,856	10,284
Actual lime requirement 1921	1,639	3,469	4,181

Base exchange studies as a rule deal with solutions many times more concentrated than actually exist under normal soil conditions. It is exceedingly doubtful that the very dilute nitric acid solution formed as the result of soil nitrification will attack to any appreciable extent the bases associated with the absorbing complex. Let us assume for the sake of discussion, however, that the three reactions indicated above actually take place. The third reaction probably plays a minor part in the development of a permanent measurable acidity or lime requirement. By the process of selective absorption, both in case of soil micro-organisms and the higher plants, the NO_3 anions are absorbed and the associated Ca cations are returned to the soil solution probably as calcium bicarbonate. The Ca removed from the absorbing complex by the action of nitric acid indicated in reaction 3 is again returned to the soil to combine with the H_2X formed. In other words, the final reaction is similar in effect to that which takes place in case of reaction 1 in which the Ca displaced by $(NH_4)_2$ combines with the sulfuric acid formed.

On the basis of the average calcium content of the crops grown in the Pennsylvania grain rotation, the total calcium removed can account for only 18% of the nitrogen assimulated on the basis of $Ca(NO_3)_2$. It is quite probable that the calcium removed by the plants is derived from the bicarbonate form rather than that combined as calcium nitrate.

It is obvious from the above discussion that the calcium lost by drainage combined in the nitrate form would reduce that returned to the absorbing complex as the result of selective absorption. This loss of calcium is in part compensated by that present other than that associated with the absorbing complex. Thus, the decay of crop residues (roots and stubble) returns to the soil solution ash constituents, part of which may be derived from the sub-soil.

On the basis of the above discussion it is of interest to compare the actual lime requirement with the theoretical based on the formation of 1 molecule of dibasic acid for each molecule of ammonium

sulfate applied. (In terms of $CaCO_3$, the pounds of ammonium sulfate applied multiplied by 0.757.) Table 3 shows such a comparison.

TABLE 3.—*Theoretical lime requirement (1 H_2X) based on reactions 1 and 2 compared to the actual lime requirement found at three periods of the experiment.*

	Plat 30 (24N)	Plat 31 (48N)	Plat 32 (72N)
Theoretical lime requirement 1910	1,199	2,398	3,597
Actual lime requirement 1910	1,074	2,433	2,883
Theoretical lime requirement 1915	1,456	2,962	4,368
Actual lime requirement 1915	1,372	2,757	3,991
Theoretical lime requirement 1921	1,714	3,428	5,142
Actual lime requirement 1921	1,639	3,469	4,181
Average theoretical	1,456	2,929	4,369
Average actual	1,362	2,887	3,685
Difference	94	42	684
pH—Tier 1, 1921	4.95	4.63	4.55

The above data show that there exists a remarkably close correlation between the theoretical lime requirement and that actually found. Since this close relationship exists in case of each of the three periods in which two different methods of measuring lime requirement were used, we may conclude that the correlation is not the result of mere coincidence, but rather is due to a definite relationship. It is of interest to note that the average differences between the theoretical and actual lime requirements of Table 3 represent less than 1 cc of N/28 lime water in terms of the Veitch method, and also less than 1 cc of N/50 sodium hydroxide in terms of the author's lime requirement method.

The pounds per acre of $CaCO_3$ required per 100 pounds of pure ammonium sulfate applied were found to be as follows:

	Plat 30 (24N)	Plat 31 (48N)	Plat 32 (72N)
1881–1910 (29 years)	67.7	76.7	60.7
1881–1915 (34 years)	71.3	71.7	69.2
1881–1921 (40 years)	72.4	76.6	61.6
Average	70.5	75.0	63.8
Theoretical (1 H_2X)		75.7	

The above data show that the actual lime requirement ($CaCO_3$) factor bears a close relationship to the theoretical, based on 1 H_2X or the pounds per acre of ammonium sulfate multiplied by 0.757. The relatively lower figure in the case of plat 30 is due no doubt to the fact that the H_2X formed as the result of the first two reactions has in part been replaced by Ca present in excess. This is borne out by the fact that on tier 2 the east end of the ammonium sulfate plats is still alkaline after 40 years due to the excess of lime derived from the underlying parent rock which is near the surface. The plat which has

received the heaviest application of ammonium sulfate shows the lowest factor. This may be due in part to the fact that a greater proportion of the ammonia is utilized by the soil fungi under more acid conditions. In other words, under field conditions relatively less of the ammonium cations enter the soil-absorbing complex in which case the H_2X formed by the nitrification or removal of the absorbed ammonium would not be in proportion to the ammonium actually applied to the soil. The early exhaustion of the excess of lime in case of the heaviest application of ammonium sulfate complicates the situation. Acidity is the product of physical, chemical, and biological action. The progressive increase in soil acidity brings about a continued reorganization of the micro flora of the soil. The trend is toward the development of the fungi population at the expense of the bacteria. In any event, the condition is an exceedingly complicated one which can, on the basis of our present knowledge, be explained only by theory. It will be of considerable scientific interest to follow the trend of these old plats and to determine the changes of relationship with further applications of ammonium sulfate. It is planned to sample these plats again in 1931 which will create a fourth period representing half a century of continuous treatment.

It is of interest to study the replaceable cations in relation to each of the three rates of ammonium sulfate application. Table 4 shows such a study. Two hundred grams of air-dry soil were shaken for 1 hour with a liter of normal ammonium sulfate.

TABLE 4.—*Milligram equivalent of exchangeable cations in 100 grams of soil, replaced by a normal solution of ammonium sulfate.**

Replaceable cations	Plat 30 (24N)	Plat 31 (48N)	Plat 32 (72N)
Al	1.00	2.64	2.97
Fe	0.40	0.96	0.46
Ca	1.34	0.68	0.67
Mg	0.86	1.16	1.20

*Analysis by F. J. Holben.

It is of interest to note that the soil of plat 30 contains twice the replaceable Ca cations found in the soils of plats 31 and 32. The replaceable or exchangeable Al, however, is in reverse order to that of Ca. These data serve to emphasize the fact that the increased applications of ammonium sulfate tend to exhaust the replaceable Ca and accordingly increase the exchangeable Al. Further studies are now in progress dealing with a more detailed study of these old plats with respect to exchangeable cations.

SUMMARY

Ammonium sulfate, under the conditions of the Pennsylvania field plat experiment, increased soil acidity in proportion to the equivalent of 1 molecule of dibasic acid for each molecule of ammonium sulfate applied.

The theoretical lime requirement based on the formation of one affective molecule of dibasic acid for each molecule of ammonium sulfate applied compares with the average actual lime requirement as follows:

	Plat 30	Plat 31	Plat 32
Theoretical lime requirement	1,456	2,929	4,369
Actual lime requirement	1,362	2,887	3,685

The average difference between the theoretical lime requirement (pounds of ammonium sulfate multiplied by 0.757) and that actually found represents less than 1 cc of N/28 lime water or 1 cc of N/50 sodium hydroxide in terms of the author's method.

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THE COMPARATIVE EFFECTS OF CONCENTRATED NITROGENOUS FERTILIZERS ON PERMANENT SOIL ACIDITY[1]

F. E. ALLISON[2]

The rapid increase in the use of various synthetic nitrogenous salts as fertilizers during the past few years has stimulated an interest in the effect of these on soil acidity, and numerous greenhouse and field studies have been made in an attempt to determine these effects. The results have not always been in agreement, as might be expected, since so many variables enter in. Apparently, many of the supposedly discordant results are actually consistent when proper allowance is made for all the important variables involved. The purpose of this paper is to present a theoretical discussion of the effect of the various types of nitrogenous materials on soil acidity with an analysis of certain of the factors that have previously received too little consideration. It is hoped that this will aid in the interpretation of some of the experimental data already reported and possibly serve as a guide in outlining new experiments along this line.

In beginning any discussion of the effect of fertilizers on soil acidity it is necessary to define what is meant by the true acidity effect of a fertilizer. There are at least two possible viewpoints which for convenience will be called absolute and comparative effects. By absolute effect is meant the sum total of all the direct and indirect acidity effects caused by the application of a single fertilizer material. This would include the total acidity brought about by every factor mentioned on the following pages as well as that resulting from indirect causes, many of which are not mentioned here. It is well known that in nature a soil is normally in a state of equilibrium or nearly so under the prevailing conditions. Any physical or chemical treatment may disturb this equilibrium and set in motion a series of changes in which each is dependent upon the preceding. Many of these are intangible and not readily subject to quantitative analysis, yet if increased acidity results from them then in the absolute sense the fertilizer is the cause of the acidity. The comparative effeet

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Received for publication April 7, 1931.

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represents not the effect of a single material, but rather the difference in effect between two materials or between a single material and a suitable check (where soil nitrogen is present). In the case of cropped soils the comparative effect must be based on equal yields for the various treatments. Under experimental conditions equal yields are seldom obtained, hence corrections must be made for the variations, as will be explained later. While such corrections are necessary in order to obtain a true comparative effect, there would be no such corrections when dealing with the absolute effect.

This paper will deal wholly with the comparative effects of various nitrogenous fertilizers on soil acidity. By assuming this viewpoint, which is the usual one taken by those who have considered the subject, we confine the discussion largely to the major factors involved, namely, quantity and nature of the basic or acidic radical added in the fertilizer in combination with the radical containing the nitrogen, nitrification, effect of the crop, and leaching. It is true that even though we consider only the comparative effects of nitrogenous fertilizers on acidity we do not eliminate entirely the intangible effects. It is believed, however, that the intangible fertilizer effects do not vary greatly between soils treated exactly alike except for the source of nitrogen.

In the following discussion all references to the effect of a material on soil acidity are based on permanent quantitative acidity, usually expressed in terms of titratable acidity, and not to soil reaction, expressed as pH, unless pH is specifically mentioned. Titratable acidity, determined by a number of methods, represents the exchangeable hydrogen brought into solution by the treatment of a soil with suitable neutral salts. This hydrogen is titrated to an end point near pH 7. It is realized that even the term titratable acidity is not entirely satisfactory, since none of the titration methods gives strictly quantitative results under all conditions of salt concentration, varying soil types, and different reactions. Furthermore, there is at least some evidence that non-exchangeable hydrogen may become exchangeable and possibly the reverse process may occur, although this is still a disputed point. If the state of the hydrogen can shift this would, of course, affect titratable acidity, particularly in experiments where the soil is allowed to stand for months or years between determinations.

THEORETICAL POSSIBILITIES

When a nitrogenous fertilizer is added to a soil, particularly in the field where a crop is grown, it may undergo so many transfor-

mations that it might seem almost impossible to determine the possible net effect on soil acidity with any reasonable degree of accuracy. A careful study of the subject has convinced the writer, however, that under ordinary conditions only a comparatively few of the many possibilities exert a marked effect. An attempt will be made here to analyze the outstanding theoretical possibilities, and point out the factors or agencies at work which need to be given major consideration in estimating the comparative acidifying effects of materials under different experimental or practical conditions. This phase of the discussion will deal, first, with what happens where a fertilizer is applied to an uncropped soil; and second, with the effect of the crop alone through its removal of ions from the soil.

UNCROPPED SOILS

When a nitrogenous fertilizer is added to an uncropped soil one or more of the changes outlined in Table 1 may take place. There are other possibilities, but it is believed that the ones listed are by far the most important. The maximum quantities of base required to neutralize the acidity which may develop from several materials, according to each of the possibilities listed, are also given. The data of Table 1 are expressed in terms of pounds of CaO required per pound of nitrogen added. The equations given below illustrate the type of reaction which may occur in soil, assuming complete nitrification of ammonium sulfate.

$$(NH_4)_2SO_4 + CaX_2 \longrightarrow CaSO_4 + 2NH_4X \qquad (1)$$
$$2NH_4X + O_2 \longrightarrow 2HNO_3 + 2HX + 2H_2O \qquad (2)$$
$$2HNO_3 + CaX_2 \longrightarrow Ca(NO_3)_2 + 2HX \qquad (3)$$

In this case, two H ions must be neutralized for every NH_4 ion added, which corresponds to 4 pounds of CaO per pound of nitrogen. Similar equations for other materials served as a basis for the calculation of the other data given in Table 1.

If an ammonium salt is added to a soil and no nitrification takes place, there is no effect on acidity if the fertilizer remains in the soil unchanged, or if it is leached out as such. This statement is, of course, quite obvious. However, in the absence of nitrification, if any agency is at work which removes the ammonia without the corresponding amount of anion, then the soil is left more acid in proportion to the quantity of anion set free, except where the nitrogen is added as urea, ammonium carbonate, or ammonium salt of an organic acid. Examples of such instances are cases B and E. With regard to case B we know that soils do lose appreciable quantities of

TABLE 1.—*Maximum quantities of base* required to neutralize the acidity from several nitrogenous fertilizers, assuming that a crop is not grown on the soil.*

Source of nitrogen	No nitrification					Nitrification		
	Unleached			Leached		Unleached		Leached
	Case A, ammonium salt remains in soil unchanged	Case B, ammonia volatilized	Case C, ammonium ion assimilated by micro-organisms†	Case D, ammonium salt leached out unchanged	Case E, ammonia leached out as ammonium carbonate	Case F, nitrate salt remains in soil unchanged	Case G, nitrate ion assimilated by micro-organisms†	Case H, nitrate salt leached out
Ammonium sulfate	0	2	2	0	2	4	2	4
Mono-ammonium phosphate	0	6	6	0	6	8	6	8
Di-ammonium phosphate	0	3	3	0	3	5	3	5
Ammonium nitrate	0	2	2	0	2	4	0	4
Urea	0	0‡	0‡	0	0	2‡	0‡	2‡
Ammonium carbonate	0	0‡	0‡	0	0	2‡	0‡	2‡
Proteins	–	–	–	–	–	2	0	2
Sodium nitrate	–	–	–	–	–	0	—2	0
Calcium nitrate	–	–	–	–	–	0	—2	0

*All figures represent pounds of CaO required to neutralize the acidity per pound of nitrogen added.

†Since in these cases the nitrogen is still left in the soil, it may be nitrified later and develop the full acidity corresponding to cases F and H.

‡These quantities of base are calculated on the assumption that CO_2 has no effect on permanent titratable acidity.

gaseous ammonia under certain conditions, but there is practically no quantitative data on the subject. The extent of the loss of ammonia by leaching (cases D and E) is practically negligible. If there is any appreciable quantity of colloidal matter in a given soil, the ammonia is absorbed and can not be extracted by leaching. The removal of ammonia as a result of assimilation by micro-organisms (case C) undoubtedly takes place to a considerable extent, especially under conditions where nitrification is slow or where considerable easily decomposable sources of energy are present. The ammonia so absorbed is converted into organic nitrogen, mostly proteins, which will temporarily affect acidity as shown in case C. This nitrogen is not removed from the soil, however, and will be available for ammonification and nitrification later after the organisms die.

Where nitrogenous fertilization occurs under fallow conditions ordinarily the nitrogen will accumulate as nitrates fairly rapidly. Either the nitrate salts may remain in the soil unchanged (case F) or be leached out (case H). The effect on acidity, shown in Table 1, is the same in either case and represents the maximum increase in acidity possible under any conceivable condition. Another possibility is that the nitrate ion or nitric acid may be assimilated by the soil micro-organisms, which would temporarily, but not permanently, affect acidity, as already explained.

The calculations, as given in Table 1, are based on the assumption that CO_2 has no effect on permanent soil acidity. The evidence indicates that from a practical fertilizer standpoint this is essentially true for most soils of the humid region but possibly not in semi-arid soils. Neutral base-saturated soils will progressively give up their calcium when leached with carbonated water and take up an equivalent amount of hydrogen ions. This will presumably continue only until the H-ion concentration of the soil equals that of the carbonated water. This leaching action of carbonated waters is largely responsible for the slow development of acidity in humid regions. These soils, as a result of long-continued leaching, are practically in equilibrium with the carbonic acid of the soil solution, constantly being produced by micro-organisms and the roots of higher plants. Hence, any additional CO_2 supplied in the fertilizer as urea, ammonium carbonate, or ammonium salts of organic acids, would produce a negligible effect. Under semi-arid conditions where soils are not acid the effect of CO_2 might be appreciable. Even this is questionable, however, since the quantity of CO_2 normally produced in soils is large in proportion to that supplied in fertilizers, and since these soils are not subject to appreciable leaching.

THE PLANT AS A FACTOR

Nitrogenous fertilizers are usually applied only to cropped soils or just prior to planting. A portion of this nitrogen, usually considerably less than 60% under field conditions in the humid region, is absorbed by plants. The remainder is lost either through leaching or as gaseous nitrogen. In analyzing the direct effects of nitrogenous fertilizers on soil acidity we must, therefore, consider the crop as a major factor in addition to the points brought out in table 1.

When an ammonium salt is added to a soil and the nitrogen is absorbed by plants, four possibilities, listed as cases 1 to 4 in Table 2, need to be considered in estimating the probable degree of acidity (if any) that will be produced. The maximum quantities of base required to neutralize the acidity which may develop are also given in Table 2. These data are expressed in terms of pounds of CaO required per pound of nitrogen added, corresponding to the figures of Table 1.

In cases 1 and 3, Table 2, it is assumed that the ammonium and nitrate salts[3] are assimilated as such and that the acidic or basic

TABLE 2.—*Maximum quantities of base* required to neutralize the acidities from several nitrogenous fertilizers, assuming various possible methods of absorption of the nitrogen by the plant.*

Source of nitrogen	No nitrification		Nitrification	
	Case 1, NH_4 absorbed; anion absorbed	Case 2, NH_4 absorbed; anion not absorbed	Case 3, cation absorbed; NO_3 absorbed	Case 4, cation not absorbed; NO_3 absorbed
Ammonium sulfate	0	2	4	2
Mono-ammonium phosphate	0	6	8	6
Di-ammonium phosphate	0	3	5	3
Ammonium nitrate	0	2	4	0
Urea	0	0†	2†	0†
Ammonium carbonate	0	0†	2†	0†
Proteins	0	0	2	0
Sodium nitrate	–	–	0	—2
Calcium nitrate	–	–	0	—2

*All figures represent pounds of CaO required to neutralize the acidity per pound of nitrogen added.

†These quantities of base are calculated on the assumption that CO_2 has no effect on permanent titratable acidity.

[3]Throughout this paper where reference is made to the absorption of a salt, or compound, by plants it is merely meant to imply that an approximately equal number of the cations and anions of the dissociated salt enter the plant and not necessarily that the molecule, itself, enters as such. Probably ions are the units which actually enter. Likewise, where it is stated that free NO_3 or NH_4 ions are absorbed it is meant that in net effect HNO_3 and NH_4OH, respectively, are taken up.

radical, added together with the radical containing nitrogen, is utilized by the plant in addition to the quantities of these which the same weight of plant would normally assimilate where grown on soil nitrogen. In cases 2 and 4 it is assumed that the radical containing nitrogen enters apart from the corresponding anions and cations, respectively, and that such plants contain no larger quantities of these nitrogen-free ions than corresponding weights of such plants not receiving these fertilizers.

Considering case 1, where nitrification does not occur, we see that no acidity results from the application of any of the fertilizers where the salts are absorbed as such, provided the anion, attached to the NH_4 ion, remains in the plant. If any appreciable absorption of nitrogen occurs, according to case 1 it is probably limited to the ammonium salts of carbonic or organic acids. Since none of these acids causes permanent acidity, the net effect of the absorption of a salt, such as ammonium carbonate, by a plant according to case 1 is the same as though the nitrogen is taken up according to case 2.

Absorption according to case 2, where nitrification does not take place and where the NH_4 ion enters the plant apart from the anion with which it was originally combined, is very common. A discussion of this subject is given in a paper by Allison (1).[4] Regardless of the mechanism of the absorption the final result is the replacement of the NH_4 ion by the H ion and an increase in soil acidity if the NH_4 was originally combined with a mineral acid radical other than carbonate.

Assuming that nitrification occurs, then the nitric acid, after combining with soil bases, may enter as a salt or as free nitrate ion. If it enters in combination with cation then the maximum possible acidity is developed, according to case 3, provided the cation so absorbed stays in the plant, as already explained. If it enters as the free ion, case 4, the increase in acidity is zero, except in the case of salts like ammonium sulfate and phosphate where the mineral acid ions are left in the soil. Urea and ammonium carbonate would not cause acidity under these conditions. Where Na, K, Ca, etc., nitrates are directly added to the soil, acidity is decreased if the nitrate absorption is according to case 4. This is the usual method of absorption of the nitrogen from nitrate salts, as will be shown in later paragraphs.

CONSIDERATION OF CERTAIN EXPERIMENTAL DATA

Having considered the various theoretical possibilities dealing with the effect of fertilizers on soil acidity, a few of the results obtained in field, greenhouse, and laboratory experiments by various investigators

[4]Reference by number is to "Literature Cited," p. 908.

will be analyzed. In the consideration of these data particular attention will be given to the relative importance of various factors which are responsible for the increase (or decrease) of soil acidity following applications of nitrogenous fertilizers.

METHOD OF NITROGEN ABSORPTION BY HIGHER PLANTS AND SOIL ACIDITY

Under field conditions we know that practically all of the nitrogen applied as fertilizer, regardless of the form, is either absorbed by plants or leached out as nitrate. The removal as nitrate in the drainage water offers no difficulties so far as estimation of the effect on acidity is concerned, provided we know the quantity removed. It is concerning the manner in which plants absorb their nitrogen that the least is known. For this reason special attention is devoted to certain phases of this subject that have a bearing on soil acidity.

Most of the nitrogen absorbed by plants probably enters the roots in the nitrate form, but there is much evidence (1) to indicate that other forms of nitrogen, particularly ammonia, are utilized to a greater extent than has generally been supposed. The ammonia which enters the plant probably enters largely as the free ion without the corresponding amount of anion. The acidity, if any, that develops in this case from the various nitrogenous fertilizers corresponds to case 2, Table 2.

How does the nitrate ion enter the plant? The effect of the various fertilizers on soil acidity under field conditions depends to a considerable extent upon the answer to this question. For instance, if urea nitrifies, the HNO_3 combines with soil bases and the nitrate ion is absorbed, together with the corresponding amount of cation, then urea depletes the soil of bases to half the extent that ammonium sulfate does. As previously explained, this statement is true only provided the cations so absorbed are retained by the plant. If all the nitrate is absorbed as free ion, i. e., with H ion instead of with base, then the nitrified urea has no direct effect on soil acidity. Fortunately there are sufficient data available to answer the purpose for this discussion. The writer has chosen to present some of the results from the Rothamsted Experiment Station.

Table 3, taken from the article by Hall and Miller (4) but with additional calculations by the writer attached, shows the quantities of bases and acids removed by four crops growing on the Rothamsted plats. Hall and Miller reduced the acids and bases to the hydrogen equivalents so as to make the figures directly comparable. In their calculations it was assumed that all of the nitrogen entered the plante as NO_3. Their comments on the table were as follows:

TABLE 3.—*Basic and acid constituents of various crops.*

	Agdell rotation, wheat, complete manure, 8 courses	Agdell rotation, barley, complete manure, 8 courses	Agdell rotation, swedes, complete manure, 3 courses	Park hay, Plat 9, 1856–73
Dry matter per acre, pounds	4,749	4,124	3,899	4,812
Nitrogen in dry matter, %	0.88	1.00	2.41	1.55
Ash in dry matter, %	4.74	4.00	6.59	7.24
Percentage Composition of Ash				
Ferric oxide	0.37	0.64	0.96	1.32
Lime	4.41	7.82	13.42	8.27
Magnesia	2.98	4.16	2.70	3.42
Potash	16.21	19.33	36.33	35.59
Soda	0.39	1.67	4.27	3.87
Phosphoric acid	9.09	12.88	9.38	7.96
Sulfuric acid	2.56	3.58	12.36	5.76
Chlorine	1.46	3.15	4.18	14.83
Silica	60.58	46.47	1.04	16.54
Constituents Reduced to Equivalents of H, and Pounds per acre				
Ferric oxide	0.03	0.04	0.09	0.17
Lime	0.36	0.46	1.24	1.03
Magnesia	0.33	0.34	0.35	0.60
Potash	0.78	0.68	1.99	2.64
Soda	0.03	0.09	0.36	0.44
Bases, total	1.53	1.61	4.03	4.88
Phosphoric acid	0.87	0.90	1.02	1.18
Sulfuric acid	0.14	0.15	0.80	0.50
Chlorine	0.09	0.15	0.30	1.47
Nitrogen	3.00	2.97	6.74	5.35
Silica	4.53	2.55	0.09	1.91
Acids, total, excluding SiO_2	4.10	4.17	8.86	8.50
Total bases	1.53	1.61	4.03	4.88
Excess of acid (as H), excluding SiO_2	2.57	2.56	4.83	3.62
Equivalent to lbs. of CaO per lb. of N	1.72	1.75	1.44	1.36
Acids, total, excluding SiO_2 and N	1.10	1.20	2.12	3.15
Excess of bases (as H), excluding SiO_2 and N	0.43	0.41	1.91	1.73
Equivalent to lbs. of CaO per lb. of N	0.29	0.28	0.57	0.65
Ratio of bases to acids:				
Exclusive of SiO_2	1:2.68	1:2.59	1:2.20	1:1.74
Exclusive of SiO_2 and N	1:0.72	1:0.75	1:0.53	1:0.65

"It will be seen that there is a considerable excess of acid in the plant, from which it follows that an equivalent amount of base was left behind in the soil. This base is, in most cases, nearly equivalent to the nitrogen taken in as nitrate, and calculated as calcium car-

bonate will amount to between 100 and 300 lbs. of calcium carbonate per acre. In other words, the normal growth of farm crops leaves behind from the salts in the soil used for its nutrition about as much base as would have been previously required for the nitrification of the nitrates which entered the plant, as measured by the nitrogen finally contained in it."

These data show, then, that practically no nitrogen was absorbed by any of the four crops according to case 3, Table 2. Presumably most of the nitrogen entered the plants as the free nitrate ion (case 4, Table 2). It is impossible, however, to say from the data that most of the nitrogen did not enter as the free ammonium ion. This is a minor point so far as this discussion is concerned since the direct effect of the fertilizer on soil acidity would be essentially the same in either case.

At the bottom of Table 3 are attached the calculations of acid-base ratio for the four crops. These figures show that plants take out a large excess of acid from the soil if the nitrogen is figured as NO_3. Where it is not considered as an acid, the total of bases removed is appreciably larger than that of the acids.

The ability of a plant continually to take more acid than base from the soil (considering that nitrogen is absorbed as HNO_3) seems on first thought rather strange. The plant takes up the NO_3 ion apart from the corresponding basic ion of the original neutral nitrate salt. This NO_3 is reduced to NH_4 which is in turn utilized by the plant in the synthesis of neutral proteins. Regardless of whether the nitrogen enters the plant as an acid or basic ion, the reaction of the ion is neutralized as a result of protein formation.

Table 3, as well as Tables 4 and 5, show that plants absorb their nitrogen largely as NO_3 or NH_4 ions, and not as salts. This means that if we assume complete absorption by plants of the nitrogen of a salt, such as ammonium sulfate, the direct effect on soil acidity is the same whether the plant takes up the nitrogen directly as ammonia or subsequent to nitrification as nitrate. In the absence of nitrification the only acid which is formed in the soil from the fertilizer is sulfuric. If nitrification occurs, both SO_4 and NO_3 ions are present for a time, but plant assimilation removes the latter. It is, therefore, only the SO_4 ion left in the soil that increases acidity in either case, neglecting the effect of the removal of extra base by the larger crop. This viewpoint is contrary to that rather generally held at present. A further discussion of the subject is given on subsequent pages.

Considerable data have been reported which substantiate the viewpoint that the removal of nitrogen from soils by crops results in a much smaller titratable acidity than if removed by leaching. This is

a further indication that the nitrogen is absorbed by the plant largely according to either case 2 or 4, Table 2. The results of Lyon and Bizzell (8, 9) to which reference is made in a later paragraph, are qualitative examples of such data.

Recently Truog (12) has presented calculations of the basic and acidic constituents of alfalfa and timothy. These are given in Table 4. The results for timothy are in very close agreement with those given by Hall and Miller for hay. It should be noted that the proportion of basic to acidic constituents absorbed by alfalfa is larger than for timothy and larger than for any of the four crops mentioned in Table 3. This might seem to indicate that the nitrogen is entering as nitrate salts rather than as free ions. Such is not the case, however, since we know in this case that most of the nitrogen enters as

TABLE 4.—*Basic and acidic constituents in water-free plant material.*

Basic constituents			Acidic constituents		
Constituents	%	O equivalent lbs. in 100 lbs.	Constituents	%	O equivalent lbs. in 100 lbs.
		Alfalfa			
Al_2O_3	0.054	0.0253	SiO_2	0.070	0.0187
Fe_2O_3	0.020	0.0060	Cl	0.100	0.0225
CaO	2.970	0.8460	P_2O_5	0.638	0.2157
MgO	0.578	0.2286	SO_3	0.527	0.1053
K_2O	2.146	0.3640	N	2.674	1.5280
Na_2O	0.208	0.0537			
MnO	0.004	0.0009			
Total	—	1.5245		—	1.8902
		Timothy			
Al_2O_3	0.053	0.0249	SiO_2	1.851	0.4910
Fe_2O_3	0.155	0.0465	Cl	0.583	0.1315
CaO	0.332	0.0947	P_2O_5	0.474	0.1602
MgO	0.220	0.0871	SO_3	0.460	0.0920
K_2O	2.190	0.3688	N	0.990	0.5657
Na_2O	0.017	0.0043			
MnO	0.006	0.0013			
Total	—	0.6276		—	1.4404

	Alfalfa	Timothy
Acids, total, excluding SiO_2	1.8715	0.9494
Total bases	1.5245	0.6276
Excess of acid (as O), excluding SiO_2	0.3470	0.3218
Equivalent to lbs. of CaO per lb. of N	0.45	1.14
Acids, total, excluding SiO_2 and N	0.3435	0.3837
Excess of bases (as O), excluding SiO_2 and N	1.1810	0.2439
Equivalent to lbs. of CaO per lb. of N	1.55	0.86
Ratio of bases to acids:		
Exclusive of SiO_2	1:1.23	1:1.51
Exclusive of SiO_2 and N	1:0.23	1:0.61

free nitrogen from the air. We know, further, that the acid-base ratio in leguminous plants is not affected appreciably by the source of nitrogen—that is, whether free nitrogen, ammonia, or nitrate salts. In the case of a legume which obtains most of its nitrogen from the air, rather than being absorbed from the soil as an acid, the growth of the crop markedly depletes the soil of bases.

The next point of interest is whether the type of nitrogenous fertilizer applied appreciably affects the manner in which the nitrogen is absorbed. For instance, is the proportion of acids to bases in plants appreciably different when they are fed on an acid-producing fertilizer than where given a base-producing fertilizer?

Table 5 gives the calculations made by the writer for certain barley plats of the Rothamsted Experiment Station which received different fertilizer treatments. The essential data are those for plat 1A fertilized with ammonium salts and for plat 1AA fertilized with sodium nitrate. The calculations for the other two plats are included as a matter of general interest only. Essentially the same conclusions can be drawn from Table 5 as from Table 3. The barley crop, regardless of fertilizer treatment, took out a large excess of acid from the soil, assuming, as Hall and Miller did, that the nitrogen entered the plant as nitrate. The ratio of bases to acids was only slightly narrower where sodium nitrate was applied than where ammonium sulfate was used. This is further evidence that the source of nitrogen does not appreciably affect the total content of basic elements in a plant.

A study of the data given in Tables 3, 4, and 5 shows that, neglecting SiO_2 and N, all crops took out more bases than acids from the soil. The data show further, at least in the case of barley, that a variation of fertilizer treatment did not markedly change the quantity of excess base removed. Under normal growing conditions apparently any given plant needs a certain excess of base for metabolic processes and the amount of this excess is not dependent upon the source of nitrogen supply. This is a very important point from the standpoint of this paper, since it shows that regardless of how nitrogen enters plants the final result corresponds essentially to case 2 or 4, Table 2. In other words, if all of the nitrogen of a fertilizer, such as urea, is absorbed by plants either before or after nitrification, no appreciable increased soil acidity results that can be attributed directly to the urea. In the case of ammonium sulfate the acidity produced corresponds to the SO_4 added and not to the SO_4 plus NO_3. In considering the above statement, it is again necessary to emphasize that this paper deals with the comparative effects of fertilizers based on equal yields. Actually, acidity will develop in the case of urea under the conditions

TABLE 5.—*Basic and acid constituents of barley grown on Hoosfield, 1882–91.*

	Plat 1A, ammonium salts alone	Plat 2A, ammonium salts +superphosphate	Plat 4A, ammonium salts +complete minerals	Plat 1AA, sodium nitrate alone	Hydrogen equivalents, lbs. per acre			
					Plat 1A	Plat 2A	Plat 4A	Plat 1AA
Grain, bu.	25.0	36.7	40.7	28.5	—	—	—	—
Grain, lbs.	1,300	1,908	2,116	1,482	—	—	—	—
Grain ash, lbs.	27.3	44.7	51.6	31.9	—	—	—	—
Straw, lbs.	1,340	1,970	2,340	1,650	—	—	—	—
Straw ash, lbs.	62.3	92.8	123.1	77.2	—	—	—	—
Bases in Grain, Lbs. per Acre								
Fe_2O_3	0.26	0.31	0.45	0.26	0.01	0.01	0.02	0.01
CaO	1.09	1.66	1.56	1.08	0.04	0.06	0.06	0.04
MgO	2.24	3.58	4.30	2.66	0.11	0.18	0.21	0.13
K_2O	7.43	11.16	14.59	8.59	0.16	0.24	0.31	0.18
Na_2O	0.74	1.30	0.23	1.04	0.02	0.04	0.01	0.03
Total	—	—	—	—	0.34	0.53	0.61	0.39
Bases in Straw, Lbs. per Acre								
Fe_2O_3	0.42	0.58	0.75	0.46	0.02	0.02	0.03	0.02
CaO	7.30	13.62	11.90	8.65	0.26	0.49	0.43	0.31
MgO	1.36	2.23	2.01	1.44	0.07	0.11	0.10	0.07
K_2O	7.93	6.65	34.68	9.75	0.17	0.14	0.76	0.21
Na_2O	6.37	10.71	2.23	10.81	0.20	0.35	0.07	0.35
Total	—	—	—	—	0.72	1.11	1.39	0.96
Total bases	—	—	—	—	1.06	1.64	2.00	1.35

	Acids In Grain, Lbs. per Acre							
P_2O_5	9.06	16.84	20.13	10.88	0.38	0.71	0.85	0.46
SO_3	0.83	0.95	1.03	0.95	0.02	0.02	0.03	0.02
Cl	0.54	0.19	0.11	0.42	0.02	0.01	0.03	0.01
N (as nitrate)*	20.80	30.53	33.86	23.71	1.49	2.18	2.42	1.69
Total	—	—	—	—	1.91	2.92	3.33	2.18
	Acids In Straw, Lbs. per Acre							
P_2O_5	1.48	3.40	3.96	1.72	0.06	0.14	0.17	0.07
SO_3	3.65	5.17	7.29	4.83	0.09	0.13	0.18	0.12
Cl	5.47	6.52	11.15	3.20	0.15	0.18	0.31	0.09
N (as nitrate)*	8.58	12.61	14.98	10.56	0.61	0.90	1.07	0.75
Total	—	—	—	—	0.91	1.35	1.73	1.03
Acids, total, excluding SiO_2					2.82	4.27	5.06	3.21
Total bases					1.06	1.64	2.00	1.35
Excess of acid (as H), excluding SiO_2					1.76	2.63	3.06	1.86
Equivalent to lbs. of CaO per lb. of N					1.68	1.71	1.75	1.53
Acids, total, excluding SiO_2 and N					0.72	1.19	1.57	0.77
Excess of bases (as H), excluding SiO_2 and N					0.34	0.45	0.43	0.58
Equivalent to lbs. of CaO per lb. of N					0.32	0.29	0.25	0.47
Ratio of bases to acids:								
Exclusive of SiO_2					1:2.66	1:2.60	1:2.53	1:2.38
Exclusive of SiO_2 and N					1:0.68	1:0.73	1:0.79	1:0.57

*Nitrogen analyses of crop not available; calculations based on grain 1.6% N and straw 0.64% N.

mentioned above, but it will be due to removal of base by the larger crop. Likewise, in the case of ammonium sulfate, more acidity than the equivalent of the SO_4 will develop for the same reason. However, the quantity of base removed by a given crop depends primarily upon the total nitrogen assimilated and not upon the source of the nitrogen.

In Tables 3, 4, and 5 the increases in soil acidity due to the crop, expressed in terms of pounds of CaO per pound of nitrogen in the crop, were as follows: Barley, 0.25–0.47; wheat, 0.29; swedes, 0.57; hay, 0.65; timothy, 0.86; and alfalfa, 1.55. These figures show that regardless of whether the nitrogen is obtained from the air, urea, ammonium sulfate, or any other source, the soil acidity observed by the usual methods is higher than the theoretical (case 4, Table 2) by some such amount as given for each of the crops mentioned. This means that under the experimental conditions ammonium sulfate would produce an actual acidity of approximately 2.29 pounds of CaO per pound of nitrogen absorbed by wheat in contrast to 3.55 pounds for alfalfa, making no allowance for leaching. The corresponding figures for urea would be 0.29 and 1.55 pounds. This difference between theoretical and actual figures is due entirely to the crop and not to the specific fertilizer used. The figures would vary for every crop independently of the nitrogen supply and for the same crop harvested at different stages of maturity.

MISCELLANEOUS FIELD EXPERIMENTS

In considering the results of any ordinary field experiments dealing with soil acidity it is well to remember that there is not just one variable factor but many, and often these other factors are more important than the fertilizer being studied. Some of the more important of these variables are as follows: (a) It is not unusual for unfertilized soils to lose 500 to 1,000 pounds of $CaCO_3$ per acre annually, and this quantity varies widely. The acidity due to fertilizer is therefore relatively small. (b) The more acid the soil, the less base there is removed by leaching. (c) Only about half of the nitrogen applied is recovered in the crop, the remainder being lost by leaching as nitrate and by volatilization. (d) The continued use of a fertilizer usually affects the subsoil to a considerable depth, making it impossible or at least very difficult to determine accurately the acidity resulting from the fertilizer. (e) The results of any fertilizer acidity experiment are too high unless a correction is made for the crop as determined by its acid-base ratio. It is obvious, therefore, that ordinary field experiments are practically worthless so far as showing quantitatively the comparative effects of different nitrogenous fertilizers on soil acidity.

They must be considered as of qualitative value only. Nevertheless. the results of a few experiments will be reported.

Hall and Miller (4) analyzed the results from several of the Rothamsted plats and found that, as an average, 200 pounds of ammonium salts caused a loss of 117 pounds of $CaCO_3$. This corresponds to 1.4 pounds of CaO per pound of nitrogen and represents even less base than required to neutralize the added sulfuric acid alone without making allowance for the extra base requirements of the crops and for leaching. On the other hand, sodium nitrate greatly conserved calcium. On the Broadbalk field a loss of 564 pounds per acre of $CaCO_3$

TABLE 6.—*Lime requirement in pounds of $CaCO_3$ of cropped plats continuously fertilized with ammonium sulfate for 40 years.*

	No fertilizer	P and K	Sodium nitrate + P and K			Ammonium sulfate + P and K		
			24 lbs. N	48 lbs. N	72 lbs. N	24 lbs. N	48 lbs. N	72 lbs. N
After 29 years	445	1,066	1,131	1,033	912	2,140	3,499	3,949
After 40 years	1,452	2,939	2,547	2,642	2,612	4,578	6,408	7,120
Increase due to N added:								
29 years	—	—	65	-33	-154	1,074	2,433	2,883
40 years	—	—	-392	-297	-327	1,639	3,469	4,181
Lbs. CaO per lb. N:								
29 years*	—	—	0.05	-0.01	-0.04	1.79	2.03	1.60
40 years*	—	—	-0.23	-0.09	-0.06	1.91	2.02	1.63
Theoretical (case 4, Table 2)	—	—	-2.0	-2.0	-2.0	2.0	2.0	2.0
pH after 40 years	5.58	5.42	5.78	5.58	5.64	4.95	4.63	4.55

*No correction made for acidifying effect of the crop.

occurred on the nitrate plat against 800 pounds on the unmanured plat. On the Hoos field the loss was 465 pounds against 675 pounds on the plat receiving the same minerals without nitrate. These data can not be considered as very accurate for the reasons mentioned by Hall and Miller. These investigators also point out that organic manures which contain calcium will also have an effect similar to sodium nitrate since the calcium is left behind in the soil when the calcium salts of the organic acids are decomposed.

White (13) recently reported the results of studies on the ammonium sulfate field plats at the Pennsylvania Agricultural Experiment Station. These plats grew corn, oats, wheat, and hay in rota, tion for 40 years without the application of lime. Ammonium sulfate together with phosphate and potash, was applied only to the corn

and wheat in the rotation. Table 6 shows the results of lime requirement determinations at the end of both 29 and 40 years. The corresponding results for sodium nitrate are included for comparison.

It will be observed that the acidity produced by ammonium sulfate, according to Table 6, corresponded not only to less than the SO_4 plus NO_3 involved, but on the average to less than even the SO_4 alone. White was apparently at somewhat of a loss to explain these results. From the discussion given in connection with Tables 1 and 2 and more especially in the preceding paragraphs, the explanation would seem to be evident. Field experiments conducted under humid conditions can not be expected to give quantitative results and whether the results obtained in the case of ammonium sulfate correspond to the SO_4, to the SO_4 plus NO_3, or to some other figure is largely circumstantial. (See a to e above, especially a.)

Suppose, however, that we assume that the data can be analyzed quantitatively. In this case we must first subtract at least 0.25 pound CaO per pound of ammonium sulfate nitrogen applied to correct for the extra base removed by the larger crop. This would make White's average acidity results for ammonium sulfate correspond to about 1.6 pounds CaO per pound of nitrogen added. On the other hand, considerable nitrogen was probably lost through leaching[5] as nitrate, making the theoretical acidity higher than that corresponding to the SO_4 added. If 25% of the added nitrogen was leached out as nitrate, the acidity caused by the ammonium sulfate should theoretically have corresponded to about 2.5 pound CaO per pound of nitrogen applied. In considering the reasons for the low acidities obtained by White emphasis should be placed on the fact that the ammonium sulfate increased the H-ion concentration of the soil and thus decreased the loss of base through leaching.

Furthermore, determinations were probably made on samples of soil drawn to the plowed depth. Studies elsewhere have indicated

[5]In returning the manuscript of this paper, which was sent to Dr. White for his criticisms after the Washington meeting at which his paper was given, he pointed out that during the 4-year rotation at the Pennsylvania Station the soil was covered with a sod for a period of 33 months. Dr. White believed that during this time leaching was probably not a very important factor. If so, the theoretical acidity was near 2.0 pounds CaO per pound of ammonium sulfate nitrogen added rather than 2.5 or higher as suggested here, making his results somewhat nearer the theoretical than this discussion would indicate. Incidentally, it should be stated that in his reply Dr. White was inclined to agree with the idea suggested in this paper, namely, that where plants absorb all the nitrogen of ammonium sulfate the theoretical acidity should correspond approximately to the SO_4 added rather than to the SO_4 plus NO_3. Selective absorption of ions (case 2 or 4, Table 2) is, of course, the reason for this.

that the continued use of ammonium sulfate affects the subsoil sometimes to a considerable depth. The failure of sodium nitrate to exert its theoretical neutralizing power may be explained in a similar manner. Probably a fourth to a half of the sodium nitrate was leached out and hence had no effect on acidity. The acid-base ratio of the crop would account for an additional 0.25 pound CaO per pound of nitrogen added, while the fact that sodium nitrate decreased the H-ion concentration of the soil would allow more leaching of base to occur.

Hartwell and Damon (6) compared ammonium sulfate and sodium nitrate on field plats over a period of 34 years during which time lime was added at frequent intervals. It was found that 3 pounds more of CaO were required per pound of nitrogen in the form of ammonium sulfate than the same amount applied as sodium nitrate. In terms of pounds of CaO per pound of nitrogen the possibilities in this case are as follows:

	Nitrogen leached out as nitrate	Nitrogen removed in crop Case 3, Table 2	Nitrogen removed in crop Case 4, Table 2
Ammonium sulfate	4	4	2
Sodium nitrate	0	0	—2
Difference	4	4	4

The situation is rather unusual where the results are reported in terms of the difference between an acid-producing and a base-producing fertilizer. In this case the theoretical difference in soil acidity between the two materials is the same whether the nitrogen is all leached out or all absorbed by the crop. Such data fail to throw any light on the form in which the nitrogen enters the plant or on the quantity lost by leaching. Furthermore, there is no effect of crop to be considered if we assume equal yields with the two fertilizers. The crop exerts an effect (removes more base than acid, neglecting N and SiO_2), of course, but equally in both cases so that it does not enter into the difference. Theoretically the difference between the acidity produced by sodium nitrate and ammonium sulfate should be 4 pounds CaO per pound of nitrogen. Hartwell and Damon actually obtained a figure of 3. The authors point out, however, that slightly more lime would probably have been required if the two plats had been kept at exactly the same pH throughout the whole experiment. In addition, the effect of the fertilizers on the subsoil represents a variable and unknown quantity.

Burgess (3) found that nitrate of soda and ground starfish decidedly reduced soil acidity on cropped soils, while the common

organic sources of nitrogen (dried blood, tankage, etc.) slightly, but consistently, increased it. Sulfate of ammonia wherever compared with other carriers of nitrogen always greatly increased soil acidity.

Morse (10) reports the results of calcium analyses from the drainage water of cropped plats variously fertilized for 9 years. The experiment was conducted in a manner similar to those at Rothamsted. The results, expressed in p. p. m., were as follows: Unmanured soil, 36.5; ammonium sulfate, 54.2; and sodium nitrate, 24.8. The results of the analyses of the drainage waters were corroborated by analyses of the residual $CaCO_3$ in the surface soil of each plat. The pounds of $CaCO_3$ per acre 6 inches were for the no nitrogen plat, 1,183; for the ammonium sulfate plat, 777; and for the sodium nitrate plat, 1,585. In this case sodium nitrate conserved calcium to almost the exact extent that ammonium sulfate removed it. These data mean little, however, so far as this discussion is concerned since calcium analyses alone do not give a true picture of titratable acidity.

GREENHOUSE EXPERIMENTS OF PIERRE

The greenhouse experiments recently reported by Pierre (11) deserve rather detailed consideration since the data represent the results of carefully conducted experiments to determine quantitatively the effect of various nitrogenous fertilizers on soil acidity. The reader should refer to the original articles for the details of the experimental procedure. The essential points are that four crops (oats, corn, sorghum, and vetch) were grown in rotation in pots to which applications of nitrogen equivalent to 1,110 and 1,430 pounds of ammonium sulfate per 2,000,000 pounds of soil were made. This fertilizer treatment was given to each crop except to the vetch. Phosphate and potash were also applied to all pots receiving nitrogen. Exchangeable hydrogen determinations were made on the soils of the various pots at the end of the experiment.

In considering all of Pierre's data it is necessary to bear in mind the conditions that are of prime importance, *viz.*, (a) absence of leaching as a factor, (b) warm greenhouse conditions where nitrification is rapid provided the acidity is not too high, (c) continuously cropped soils, (d) presence of excess of potash and phosphate, and (e) acid-base ratio of crops grown.

In one of Pierre's experiments lime in various quantities, together with a constant amount of ammonium sulfate, was added and from these data the quantity necessary to neutralize the acidity due to 1 pound of ammonium sulfate was calculated. Table 7 is a recalculation of Pierre's data. Theoretically, assuming case 4, Table 2, 1 pound of

nitrogen as ammonium sulfate should require 2 pounds of CaO to neutralize the acidity which would develop. Table 7 shows that 2.62 pounds CaO were actually required. Other experiments by Pierre on five other soils likewise gave similar or slightly higher values. These excellent data give an idea of the magnitude of the effect of the crop, independent of source of nitrogen, on soil acidity. This effect (2.62–2.00) amounts to 0.62 pound of CaO per pound of nitrogen. This figure, which is an average of four crops including three grains and one legume, is about what would be expected from the data previously given for various crops. Very likely the crops were not grown to maturity in the greenhouse, which would make the figure higher than normal. This is due to the fact that immature grain crops contain a higher proportion of bases with respect to acids than is the case at maturity. Of course, other factors influence the results to some extent, so that the 0.62 figure can not be considered as strictly quantitative.

TABLE 7.—*The H-ion concentration and exchangeable hydrogen of a cropped Cecil clay loam fertilized with ammonium sulfate and various amounts of calcium carbonate.*

Ratio between amounts of ammonium sulfate and calcium carbonate applied	pH	Exchangeable hydrogen mgm. equiv.	Lime necessary to neutralize acidity	
			Lbs. $CaCO_3$ per 1 lb. ammonium sulfate*	Lbs. CaO per 1 lb. of nitrogen*
No fertilizer	6.03	3.75	—	—
No nitrogen	5.90	4.10	—	—
1 to 0.0	4.80	6.45	—	—
1 to 0.5	5.15	5.35	1.1	2.82
1 to 1.0	5.83	4.20	1.0	2.76
1 to 1.5	6.40	2.65	0.9	2.45
1 to 2.0	6.90	1.40	0.9	2.46
Average	—	—	1.0	2.62

*Calculated from exchangeable hydrogen data.

The results of Table 7 show, then, that ammonium sulfate under the conditions developed an acidity corresponding almost exactly to the SO_4 added and that the NH_4 had no effect on acidity, except that it increased the yield and caused greater demands on the part of the crop for soil bases.

In Table 8 are given the recalculations of other data obtained by Pierre in an experiment in which a comparison was made of various sources of nitrogen. In addition to the actual data reported by Pierre calculations by the writer are also included in which the effect of the

TABLE 8.—*The H-ion concentration and exchangeable hydrogen of a cropped Cecil clay loam treated with various nitrogenous fertilizers.*

Source of nitrogen	pH	Exchangeable hydrogen						Lbs. CaO required per lb. of nitrogen		
		Barium acetate method			Titration method					
		Actual		Corrected, relative*	Actual		Corrected, relative*	Theoretical (case 4 Table 2)	By barium acetate method, corrected*	By titration method, corrected*
		Total, mgm. equiv.	Relative		Total, mgm. equiv.	Relative				
No fertilizer	6.03	3.75	—	—	3.26	—	—	—	—	—
No nitrogen†	5.90	4.10	—	—	3.74§	—	—	—	—	—
Ammonium sulfate	4.80	6.45	100	100	7.00	100	100	2	2.00	2.00
Ammonium phosphate	5.15	7.80	157	175	7.00	100	100	6	3.51	2.00
Leunasaltpeter‡	5.00	5.80	72	64	6.00	69	60	1	1.27	1.20
Ammonium nitrate	5.48	5.25	49	33	4.76	31	10	0	0.66	0.20
Urea	5.45	5.10	43	25	5.00	39	20	0	0.49	0.39
Sodium nitrate	6.60	2.60	—64	—115	—	—	—	—2	—2.30	—
Calcium nitrate	6.30	2.70	—60	—109	—	—	—	—2	—2.19	—
Calcium cyanamid	6.54	2.25	—79	—135	—	—	—	—2+	—2.69	—

*These calculations are based on the assumption that the actual results for all pots receiving nitrogen are high by a figure corresponding to 0.62 lb. CaO per lb. of nitrogen, due to crop, as shown in Table 7.

†Received superphosphate and muriate of potash at same rates as did pots receiving nitrogenous fertilizers.

‡Ammonium sulfate and ammonium nitrate in equal molecular proportions.

§Estimated.

crop is deducted. This effect was considered in the calculations as amounting to 0.62 lb. CaO per pound of nitrogen, as shown in Table 7.

The summary of the results, after making allowance for the crop, is shown in the last two columns of Table 8. Considering the experimental difficulties involved in such an experiment as this, the data for all materials, except ammonium phosphate, agree remarkably well with the theoretical. Phosphates will be discussed in a later paragraph. So many factors need to be considered, especially in an experiment lasting over a period of 2 years, that soil acidity results can, at best, only approximate quantitative results. Furthemore, as already pointed out, no methods for determining titratable acidity now available give strictly quantitative results under all conditions of pH, salt concentrations, soil types, etc.

The data of Table 8 would seem to justify the conclusion that under greenhouse conditions, where the crop absorbs all of the nitrogen added, any increase in titratable acidity caused by a nitrogenous fertilizer is due to the mineral acid radical (other than carbonate), if any, added in combination with the radical containing nitrogen. Likewise, any reduction in permanent titratable acidity is due to Ca, Mg, Na, K, etc., added as nitrates in the fertilizer. These conclusions, of course, are based on comparative acidity, assuming equal crop yields, rather than on absolute acidity.

Pierre reported additional data on the exchangeable hydrogen of three other soils which received various nitrogenous fertilizers. Some of the experimental details necessary for a proper interpretation of these experiments are lacking, but apparently the results agree closely with those reported in Table 8, if interpreted in the same manner. Theoretically, under greenhouse conditions, the soil type should be of no importance so far as titratable acidity is concerned, although it would affect the accuracy of the method used for determining it. Actually, Pierre's results agree largely with theory.

A few remarks regarding mono-ammonium phosphate are necessary. According to Table 2 this material is capable of producing two or three times as much acidity as ammonium sulfate per unit of nitrogen. Actual results reported by Pierre and others, however, show acidities corresponding closely to the results for ammonium sulfate. This is in agreement with what would logically be expected, considering the weak ionization of phosphoric acid. When ammonia is added to a weak solution of it the first H is neutralized at about pH 4.4, the second at 7.8, and the third at 9.4. Under normal conditions, then, only one-third of the maximum acidity of mono-ammonium phosphate would ordinarily be realized in the soil.

It will be observed that the conclusions drawn by the writer from Pierre's data are quite different from those given by Pierre himself. He was of the opinion that the acidity caused by ammonium sulfate, for instance, corresponds to the H_2SO_4 and HNO_3 which develop on nitrification, even though the crop absorbs the nitrogen. The writer concludes that in the comparative sense the acidity which develops is due to the H_2SO_4 only, if the nitrogen is removed by a crop. Urea would produce no acidity under these conditions. Nitrification can not appreciably affect permanent soil acidity unless the nitrate salts are removed as such from the soil by leaching or otherwise; or remain in the soil permanently as nitrates. The differences between the conclusions of Pierre and those of the writer are due to the failure of Pierre to make allowance for the excess of base over acid removed by the crop, and to the fact that in his calculations Pierre considered the "no fertilizer" rather than the "no nitrogen" treatment as the check.

LABORATORY EXPERIMENTS OF KAPPEN

Determinations of the effect of various nitrogenous fertilizers on soil acidity, using the Neubauer method of culture, were reported by Kappen (7). Briefly the method consisted in adding the fertilizers to 500 grams of soil in dishes in quantities corresponding to three times that used in agricultural practice. The soil was covered with sterile sand and 100 sterile seeds planted and allowed to grow for 3 to 4 weeks. After removing the plants, including the roots, the acidity of the soil was determined by shaking with calcium acetate and titrating with NaOH. The fertilizations and cropping were repeated five times. The data are given in Table 9.

In considering the results it should be borne in mind that the only fertilizers applied were the single materials being tested. This one-sided fertilization means that the source of nitrogen was not the only variable. For instance, where ammonium sulfate was applied undoubtedly both P and K and possibly other elements were deficient and limited plant growth. On the other hand, where ammonium phosphate was used P was present in excess. Such a system of experimentation gives some sort of an acidity figure, but the results do not mean very much. Undoubtedly the plants grown on ammonium sulfate alone not only made poorer growth than on ammonium phosphate, because of lack of phosphorus, but also contained less than the normal amount of phosphorus in the dry matter. Where one fertilizer is compared with another a true acidity value is possible only where the experimental conditions are made such that the yields are essentially the same with all treatments, or else where the crop is analyzed and a correction is made for the acid-base ratio of the crop.

TABLE 9.—*Effect of various nitrogenous fertilizers on soil acidity in the presence and absence of a crop, using the Neubauer culture method.*

Fertilizer material	Hydrolytic acidity after 1 crop		pH	Hydrolytic acidity after 5 crops		pH
	Actual	Increase over check		Actual	Increase over check	
	Planted					
No fertilizer	8.6	—	6.4	9.8	—	6.0
Ammonium sulfate	9.2	0.6	6.2	18.3	8.5	4.9
Ammonium chloride	8.6	0.0	6.6	13.3	3.5	5.3
Ammonium nitrate	8.5	-0.1	6.4	12.5	2.7	5.5
Mono-ammonium phosphate	9.1	0.5	6.3	19.8	10.0	4.7
Di-ammonium phosphate	9.4	0.8	6.3	17.5	7.7	5.6
Ammoniaksuperphosphate*	9.0	0.4	6.3	20.1	10.3	4.8
No fertilizer	9.5	—	6.3	9.0	—	6.3
Potassium nitrate	9.2	-0.3	6.4	7.0	-2.0	6.6
Calcium nitrate	8.8	-0.7	6.4	6.2	-2.8	6.4
Sodium nitrate	8.8	-0.7	6.4	6.8	-2.2	7.0
Ammonium nitrate	9.8	0.3	6.3	13.1	4.1	5.7
Kaliammonsalpeter†	10.6	1.1	6.0	16.4	7.4	5.0
	Not Planted‡					
No fertilizer	8.6	—	6.5	10.0	—	5.9
Ammonium sulfate	8.9	0.3	6.1	14.3	4.3	5.2
Ammonium chloride	8.8	0.2	6.1	11.0	1.0	5.6
Ammonium nitrate	8.8	0.2	6.3	11.0	1.0	5.7
Mono-ammonium phosphate	9.2	0.6	6.0	16.3	6.3	5.2
Di-ammonium phosphate	8.7	0.1	6.4	15.7	5.7	5.7
Ammoniaksuperphosphate*	9.0	0.4	6.0	15.9	5.9	5.0

*Ammonium sulfate plus superphosphate.
†Ammonium nitrate and potassium chloride in equi-molecular proportions.
‡Figures in columns 2, 3, and 4 for one fertilization; those in columns 5, 6, and 7 for five fertilizations.

Perhaps the most striking thing brought out in Table 9 is that the acidities produced by the various fertilizers were higher in the presence of a crop. This is apparently contrary to theory. Actually, however, we lack sufficient data to interpret the results. In the case of the cropped plats we particularly need to know the percentage of the added nitrogen assimilated by the plants and the ratio of acids to bases in the dry matter. The acid-base ratio was, of course, nearly a constant for the different fertilizers, but we have no idea as to the size of the constant since the crop grown was not given. It was probably one of the small grain crops. The excess base in the crop was undoubtedly above normal, in any case, since the plants were very young when harvested. In the absence of the crop it is essential that we know the percentage of the added nitrogen present at the end of the experiment as nitrates. The most plausible explanation for the comparatively low acidities in the absence of the crop is that only a

limited quantity of the added nitrogen accumulated as nitrate, while in the presence of a crop most of the nitrogen was assimilated. The increases in apparent hydrolytic acidities of 2.7 and 4.1 for ammonium nitrate are probably due almost wholly to the increased crop, as has already been fully explained. If so, the acidities shown in Table 9 for all of the acid-producing fertilizers are high by some such figure (2.7 to 4.1), while the base-producing power of potassium, calcium, and sodium nitrates are low by a like amount. These data of Kappen are reported here not because they throw much light on the effect of fertilizers on soil acidity, but rather to emphasize the necessity for the proper planning of experiments so that the results when obtained can be interpreted quantitatively; otherwise the data may actually be misleading as is the case to a considerable extent with Kappen's results.

DISCUSSION

The facts presented above have served to emphasize the important agencies which need to be given consideration in estimating the comparative effects of various nitrogenous fertilizers on permanent soil acidity. These are (a) quantity and nature of the acidic or basic radical added in the fertilizer in combination with the radical containing nitrogen, (b) nitrification, (c) leaching, and (d) crop.

With regard to the effect of the basic or acidic radicals added, we know that so long as they remain a part of neutral salts they can have no appreciable effect on acidity, regardless of whether they stay in the soil or are leached out. The removal or chemical change of nitrogen-containing radicals, as a result of plant utilization, volatilization, or nitrification, does, however, leave the cation or anion free to exert its full effect. The basic radicals usually include Na, K, Ca, and possibly Mg, while the acid radicals include SO_4, PO_4, and Cl.

Nitrification also increases acidity in proportion to the quantity of nitrates formed. In the absence of a crop the acidity thus developed is permanent provided the nitrates remain in the soil as such or are leached out. In the presence of a crop this acidity is not permanent since the plant absorbs the NO_3 ion without the corresponding amount of cation.

Leaching is one of the most important factors in determining the acidity resulting from a given nitrogenous fertilizer. The nitrogen which leaves the soil by this method is in the form of neutral salts and hence the base removed is equivalent to the quantity of nitrates leached out, assuming that the nitrates were formed in the soil.

The importance of the crop has been emphasized on preceding pages because this factor is the least understood. The data presented

show that most of the nitrogen which enters the plant is removed from the soil as NH_4 or NO_3 ions. This means that regardless of whether the nitrogen of a material, such as urea, enters the plant before or after nitrification, no increase in soil acidity, attributable specifically to the urea, results. In the absolute sense the urea does increase acidity because it causes a larger crop yield. Again it is well to remember, however, that this paper deals with the comparative effects of different fertilizers, assuming equal yields. In this comparative sense urea does not increase acidity if all the nitrogen is assimilated by plants; the acidity is due to the crop.

Crops exert an effect in increasing soil acidity due to the fact that they remove more bases than acids from the soil, neglecting SiO_2 and N. This necessarily means that the larger the crop the more acid the soil becomes. For any given crop, such as alfalfa, the crop effect would be approximately as great in the case of one source of nitrogen as another, whether it be ammonium sulfate, sodium nitrate, soil organic nitrogen, or even atmospheric nitrogen. Unfortunately, in experimental results previously reported little or no attention has been given to the magnitude of this factor, and no corrections made for it when reporting the comparative effect of various nitrogen sources on acidity. Practically all such acidity data obtained on cropped soils have been too high. The extent of the error depends upon the crop grown, stage of maturity when harvested, and percentage of the added nitrogen recovered in the crop. Data presented here show that, under the experimental conditions, the base removal by different crops expressed in terms of pounds of CaO per pound of nitrogen in the crop varied from about 0.30 for small grains to 0.75 for hay and 1.55 for alfalfa. Theoretically, a pound of ammonia nitrogen, when completely nitrified, requires 2 pounds of CaO for neutralization. The magnitude of the base removal by crops under a given set of experimental conditions can be estimated accurately only where analyses of the crop for total nitrogen, bases, and acids are made.

This study emphasizes the extreme difficulty of determining accurately the effect of a nitrogenous fertilizer on soil acidity, particularly under field conditions where the acidity due to leaching is often many times greater than fertilizer acidity. It is certainly surprising that many investigators have obtained data in field experiments that agree fairly closely with the theoretical. In outlining new experiments it seems that two methods should be considered, namely, direct and indirect. In the direct method, such as that used by Pierre, the change in acidity of greenhouse soils is measured after a given time either by direct titration methods or by adding known

quantities of base at intervals so as to keep the pH of all pots practically the same. As already pointed out, accurate results cannot be expected where wide variations in pH occur in soils of the same series. In this direct method the titration data must be supplemented by an analysis of the crop for nitrogen, acids, and bases.

The indirect method consists in calculating the acidity (or basicity) from data showing the constituents removed from the soil by crops, leaching, or otherwise. For these calculations it is necessary to know the quantity and composition of the fertilizer materials added, the quantity of nitrogen removed from each plat and in what form, the quantity of nitrogen which accumulates as nitrate, and the analysis of the crop.

The indirect effects of fertilizers on soil acidity will vary for any given fertilizer with the nature of the soil, climate, cropping system, and many other factors which cannot be quantitatively analyzed under field conditions. Perhaps the one factor most frequently mentioned, however, is nitrification. It has often been stated that if a material such as urea nitrifies, the nitric acid will combine with soil bases and later, after the plant takes up the NO_3 ion, these basic ions will form carbonates or bicarbonates, in which form they will be more readily leached out. This idea has been greatly exaggerated. Before nitrification occurs the soil system is ordinarily in a state of equilibrium. The formation of HNO_3 slightly disturbs this equilibrium, nitrate salts then form, but immediately the plant removes the NO_3 ion and the bases are free to return to their original state. Equilibrium is reestablished. If the soil was acid at the beginning, any basic ions extracted from the base exchange complex by the nitric acid would return there when the plant assimilates the NO_3 and liberates the hydroxides of these elements. There is no reason for expecting carbonates or bicarbonates to form under such conditions. If the original soil was neutral or alkaline, then carbonates might form, but in such a soil carbonates were present originally anyway. Hence, regardless of the pH of the soil, nitrification, followed by assimilation of the NO_3, would usually leave the soil in essentially the same equilibrium as though nitrification had not occurred.

It is even possible to imagine conditions under which nitrification might add bases to the base exchange complex. For instance, if particles of $CaCO_3$ are present in an acid soil, as is not unusual, this Ca might form $Ca(NO_3)_2$, and after assimilation of the NO_3, the Ca would replace H in the base exchange complex. In considering all of these points it is well to bear in mind that nitrification and plant assimilation ordinarily proceed simultaneously and that the NO_3 ion

is removed about as fast as formed. A small quantity of basic ions might, then, be used over and over. All of the above discussion deals only with the indirect effects of nitrification, assuming complete assimilation of the NO_3 by the plant. If nitrates are leached out, then, of course, increased acidity results.

PRACTICAL CONSIDERATIONS

It is well to emphasize further that most humid soils rapidly become more acid under ordinary cropping systems, even though not fertilized. The discussion on the preceding pages does not, however, deal with this phase of the subject, except indirectly. Hall and Russell (5) state that the normal loss of calcium carbonate in the drainage water from the unmanured plats at Rothamsted amounts to about 1,000 pounds per acre annually. Lyon and Bizzell (9) found that in order to keep the supply of calcium up to its original content annual applications of 662 pounds of calcium carbonate per acre to the planted soil and 957 pounds to the bare soil were necessary. A review of a number of experiments mentioned by Lyon and Bizzell (8) showed that on the average all of the bases removed were equivalent to about 820 and 1,160 pounds of $CaCO_3$, respectively, for cropped and uncropped soils. Blair and Prince (2) found that an annual application of 800 pounds of limestone per acre kept cylinder soils near the neutral point.

Many such experiments might be mentioned which show the large losses of base from soils under cultivation, particularly where lime is added frequently or where originally present in large quantities. Of course, there is also a considerable loss of acids, particularly sulfates and chlorides, but most bases are leached out as bicarbonates and nitrates. These figures emphasize the fact that the acidity caused by the usual applications of nitrogenous fertilizers is small in comparison with the acidity due to natural agencies. The fertilizer acidity may seem large where there is an accumulative effect resulting from the use of a material, such as ammonium sulfate, over a long period of years.

The neutralization of the acidity resulting from applications of fertilizers may be accomplished by the direct application of lime to soils or by the use of fertilizer mixtures which contain basic materials. There is no objection to the use of such mixtures provided the cost per unit of plant food, making allowance for the basic material present, is no greater when actually delivered on the farm. If such non-acid-producing fertilizers are to be prepared, it will probably be desirable to compound them on the assumption that the maximum possible

acidity will develop. Any excess base will be beneficial, at least under ordinary humid conditions.

SUMMARY

1. This paper presents a theoretical discussion of the comparative effects of the addition of different concentrated nitrogenous fertilizers on permanent soil acidity, assuming equal yields for cropped soils. A definite distinction is made between the difference in the effect of two materials on acidity in contrast to the absolute effect of a single material. This discussion deals only with the comparative effect. Certain experimental data, previously reported, are discussed in the light of the facts and theories advanced. Particular emphasis is placed upon the importance of crops in relation to soil acidity.

2. *In the absence of a crop*, where the added nitrogen is either all leached out as nitrates or is left in the soil and accumulates as nitrates, the acidity which develops is theoretically the sum of the acidity due to the mineral acids (if any) added combined as nitrogenous fertilizer salts plus that caused by the nitric acid formed in the soil. These mineral acids ordinarily include only sulfuric, hydrochloric, and phosphoric. Carbonic, nitric, and nitrous acids would usually have no appreciable effect. The nitric acid of ammonium nitrate, however, would produce acidity when the NH_4 nitrifies.

3. *In the presence of a crop, assuming complete absorption of the nitrogen by the plants*, the only appreciable direct source of permanent acidity that develops under ordinary conditions that can be attributed to the nitrogenous fertilizer is the acidity caused by any of the three mineral acids mentioned, added as nitrogenous fertilizer salts. Where nitrate salts of such bases as sodium, potassium, calcium, and magnesium are added, the soil is made more basic in proportion to the quantity of the basic elements added.

4. *Under actual field conditions*, both plant absorption of nitrogen and leaching take place simultaneously and the final acidity (if any) due to the fertilizer is a weighted average of that resulting from the processes as outlined above under 2 and 3. Evidence is presented to show that under actual experimental conditions the comparative acidity or alkalinity produced by nitrogenous fertilizers does correspond rather closely to the theoretical, if allowance is made for the limitations of our methods.

5. Data are presented which show that regardless of whether a given crop is fertilized with acid-producing or base-producing nitrogenous fertilizers the proportion of bases to acids in the ash does not vary greatly.

6. The available evidence indicates that whether nitrogen enters the plant as ammonia or nitrate the final effect is as though the free ions enter. Hence, it makes no appreciable difference in final soil acidity whether the nitrogen of a salt, such as ammonium sulfate, enters the plant as ammonia or whether it is first converted into nitric acid in the soil and is then absorbed by the plant. In neither case does the nitrogen, apart from the SO_4, appreciably affect permanent soil acidity. Any increase in acidity is due to the larger crop with larger demands for basic elements as explained below.

7. Emphasis is also placed on the fact that in order to interpret accurately any soil acidity experiment, where a crop is grown and where titratable acidity determinations of the soil are made, it is necessary to know the total nitrogen content of the plant, total weight, and analysis of the ash showing the basic and acidic elements. Such data are necessary because, neglecting N and SiO_2, most plants remove more bases than acids from the soil. The acid-base ratio varies for different crops and for the same plant species at different stages of maturity. If a correction is not made for this removal of excess base, then comparative acidity calculations for different nitrogenous fertilizers will be too high. Data presented show that in the experiments discussed the excess base for several crops expressed in terms of pounds of CaO per pound of nitrogen in the crop was as follows: Barley, 0.25 to 0.47; wheat, 0.29; swedes, 0.57; hay, 0.65; timothy, 0.86; and alfalfa, 1.55. The importance of this crop factor has been largely or wholly overlooked in previous soil acidity papers. This crop effect is due strictly to the plant and shows itself to an approximately equal extent for all forms of nitrogen, including atmospheric and soil nitrogen, if we assume equal yields. Hence, it is incorrect to attribute this effect to the particular fertilizer being tested.

8. Suggestions are given regarding the best methods of conducting experiments designed to show quantitatively the effect of fertilizers on soil acidity.

9. Brief consideration is given to certain practical aspects of soil acidity. It is shown that under humid conditions the natural loss of bases from soils through leaching is so great as to make the losses due to nitrogenous fertilizers seem rather small. It is also pointed out that nitrogenous fertilizers bring about certain intangible indirect effects on acidity, but that these have been exaggerated. There is little to indicate, for instance, that nitrification causes increased acidity unless the nitrates formed are leached out or remain as such in the soil.

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SOIL RESPIRATION[1]

F. B. SMITH and P. E. BROWN[2]

The carbon dioxide content of the soil air was first determined in 1853 by Boussingault and Lewy (2)[3]. Their results stimulated the interest of other workers and, as a consequence, many investigations have been carried out to study the production of carbon dioxide in the soil, the importance of the process, and the factors influencing it.

One of the chief difficulties encountered in the work has been the development of adequate methods. From time to time, new methods have been devised, but each has left something to be desired. The fact that the concentration of carbon dioxide in the soil air does not show accurately the rate of its production has long been known and has caused much difficulty in the development of methods.

Buckingham (1), in 1904, studied the diffusion velocity of carbon dioxide through the soil and derived a formula from which the rate of production could be calculated.

Stoklasa and Ernest (8) measured the respiration intensity of soils, that is, the amount of carbon dioxide evolved from a unit weight of soil in a given time. The results were expressed as milligrams of carbon dioxide per kilogram of soil per day. The method employed involved the incubation, in large glass cylinders, of 1-kilogram portions of soil, at a given temperature and moisture content, and the determination of the amount of carbon dioxide evolved in 24 hours. The cylinders were aerated by continuous aspiration at the rate of 20 liters in 24 hours, the air being washed free of carbon dioxide before it entered the cylinder and the carbon dioxide evolved from the soil being absorbed in potassium hydroxide. The amount of carbon dioxide was determined gravimetrically. This method has been modified in many ways by subsequent workers, but it can hardly be said that it has been improved by the changes suggested.

In later field work Stoklasa and Doerell (9) used a glass bell jar, 40 cm in diameter, fitted with inlet and outlet tubes and a thermometer which extended down into the soil. The amount of carbon dioxide respired was determined as in the laboratory method.

Humfeld (4) recently used a similar method but modified the bell. Instead of aspirating with carbon dioxide-free air, he made a blank determination on the air and subtracted this amount of carbon dioxide from the total in the bell to give the amount evolved from the

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Received April 17, 1931.

[2]Assistant Professor of Soils and Professor of Soils, respectively.

[3]Reference by number is to Literature Cited, p. 916.

soil. The carbon dioxide was determined titrametrically rather than gravimetrically.

Lundegardh (5, 6, 7) worked out a volumetric method for measuring the soil respiration. He placed a conical zinc bell over the soil and collected the carbon dioxide as it escaped. Samples were taken from this bell at intervals and analyzed and the rate of respiration was calculated by means of a formula which he derived. The apparatus is unique in that the absorption of the carbon dioxide takes place in the same chamber in which it is measured. It was found that the method would allow small amounts of carbon dioxide to be determined accurately and, while open to certain objections, marks a distinct advance in the study of carbon dioxide production.

The purpose of the investigation reported here was to measure the soil respiration in different soils and under various cropping systems by the Lundegardh method in order to determine the suitability of the method for studying carbon dioxide production in the soil. Feher (3) has carried on the only tests made of the Lundegardh method and he concluded that it was not suited to field work. He modified the method by enlarging the bell and providing a means for aerating it after each determination and a Glockenapparatus was substituted for the volumetric apparatus.

EXPERIMENTAL

Laboratory and field experiments on soil respiration were carried out during 1929 and 1930 in connection with other studies on carbon dioxide production in the soil. A conical, zinc bell having a volume of 1,000 cc and an area of 189 cm was used in the first studies. The volumetric apparatus of Lundegardh was supported on a surveyor's plane table and a capillary glass tube used to connect it with the bell.

SOIL RESPIRATION IN THE LABORATORY

Preliminary work was done in the laboratory under controlled conditions to determine whether or not the accumulation of carbon dioxide under the bell was proportional to the respiration period. Four kilograms of Carrington loam were treated in a 12-liter evaporating dish with 1% of finely ground oat straw, the moisture content adjusted to 20%, and the whole incubated at 25° C for 3 days. The zinc bell was coated inside with paraffin and placed over the soil.

Three 28-cc samples of air were taken from the bell for analysis at intervals of 8 and 15 minutes. The bell was then removed, aerated, replaced, and after a definite interval, samples were taken again. This process was repeated several times. The results, expressed as grams of carbon dioxide per square meter per hour, were calculated by the formula of Lundegardh.

The average of several determinations are presented in Table 1. These results show that the accumulation of carbon dioxide under the bell has not retarded its rate of evolution. It may be noted that after incubation the soil was covered with a dense growth of molds and that the moisture content had decreased to 15%, which may have had some effect on the results secured.

TABLE 1.—*Soil respiration in the laboratory.*

	CO_2 in bell after 8 minutes, %	CO_2 in bell after 15 minutes, %	CO_2 in air, %
Sample 1	0.066	0.099	0.034
Sample 2	0.066	0.099	0.034
Grams of CO_2 per sq. meter per hour	0.200	0.217	——

RESPIRATION IN FIELD SOILS, 1929

The respiration of soils, under corn in the 4-year rotation plats was determined June 19, 1929. The corn was late and at this time was about 1 foot high. Several readings were made with the apparatus as described above. At first considerable difficulty was encountered with the volumetric apparatus because of the variations in temperature which are bound to occur when the apparatus is used in the field and is exposed to the sun and wind. The effects of differences in temperature due to those agencies may be appreciable.

The results secured are presented in Table 2. They indicate that the rate of evolution may be greatly retarded when the carbon dioxide is accumulated in a bell of this size and there is a rapid evolution. The respiration was consistently higher from the soil on plat 1300 than from the soil on the adjacent manured plat, while the concentration of carbon dioxide was 0.840% in the manured soil and 0.770% in the unmanured soil. The respiration was slightly higher on the soil which received an annual application of manure.

The respiration from the soils in the 3-year rotation series under corn was determined June 25. Ten-minute periods were used to calculate the respiration, except on two plats where it was 15 and 17 minutes. It may be noted that there were marked differences in the growth of the corn on the fertilized and unfertilized plats.

The results secured are given in Table 3. The data indicate that a rapidly growing crop may mask the effect of treatment on the soil respiration. The respiration on the manured and limed soils was increased, but with manure, lime, and rock phosphate there was no significant difference from that of the untreated soil.

TABLE 2.—*Soil respiration, 4-year rotation, 1929.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour
1300	Check	0.2788	15	0.978
		0.3191	20	0.839
1301	Manure, 8 tons once in 4 years	0.1144	10	0.594
		0.1630	15	0.564
1362	Manure, 2 tons, annual application	0.2780	10	1.443
		0.2780	14	1.031
		0.4320	22	1.021
1306	Check	0.0855	10	0.467

TABLE 3.—*Soil respiration, 3-year rotation, 1929.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour
817	Check	0.1548	10	0.843
818	Manure+lime	0.2472	10	1.339
819	Manure+lime+rock phosphate	0.1583	10	0.834
820	Crop residues+lime	0.0393	10	0.211
821	Crop residues+lime+rock phosphate	0.1548	15	0.553
822	Check	0.1548	17	0.488

The respiration from the soil on the check and the manured plats of the continuous corn series was determined on June 27 and again on all plats of this series on July 2. The 10-minute period was employed to calculate the respiration, except in two cases where a 5-minute period was used. With a longer time of accumulation on these plats, which had a high respiration, the rate of evolution was materially decreased.

The results secured in these tests are given in Table 4. The soil in the plats of this series is chiefly Carrington loam, but plats 905 and 907 border on Webster loam and plats 908 and 909 border on Carrington sandy loam. The results on the two check plats, therefore, are not entirely comparable. The difference in the respiration due to variations in the soil is quite apparent. Treatments with manure and lime stimulated the respiration, the manure being more effective than the lime.

The respiration from the soils on the plats of the 5-year rotation, which were in corn, was determined on July 2 and 3. Two soil types are represented on these plats, the checks and a part of the treated plats being on Webster loam, while the other plats are on Carrington loam. The respiration period varied from approximately 10 to 15 minutes.

TABLE 4.—*Soil respiration, continuous corn, 1929.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour	Date
905	Check	0.0276	10	0.146	June 27
906	Manure	0.0852	10	0.449	June 27
905	Check	0.2010	10	1.085	July 2
906	Manure	0.2016	5	2.176	July 2
907	Manure+lime	0.2016	5	2.716	July 2
908	Lime	0.1350	10	0.718	July 2
909	Check	0.1020	10	0.452	July 2

The results secured are presented in Table 5. It is apparent from these results that the respiration on the two soils is not comparable. The application of manure to Webster loam stimulated respiration materially. The superphosphate and rock phosphate stimulated the respiration on Carrington loam, the superphosphate being the more effective.

TABLE 5.—*Soil respiration, 5-year rotation, 1929.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour	Date
1011	Check	0.1437	14	0.546	July 2
1012	Manure	0.1630	14	0.620	July 2
1013	Manure+lime	0.0855	15	0.303	July 2
1014	Manure+lime+rock phosphate	0.0855	13	0.350	July 2
1015	Manure +lime +superphosphate	0.1140	13	0.482	July 3
1016	Check	0.1086	12	0.497	July 3
1017	Crop residues	0.1155	10	0.470	July 3
1018	Crop residues+lime	0.1244	15	0.456	July 3
1019	Crop residues+lime+rock phosphate	0.0855	11	0.427	July 3
1020	Crop residues+lime+superphosphate	0.0855	8	0.371	July 3
1021	Check	0.0855	13	0.362	July 3

RESPIRATION IN FIELD SOILS, 1930

The results secured in the field in 1929 were unsatisfactory. The apparatus is too sensitive to be used in the open and the respiration period must be varied according to the amount of carbon dioxide evolved. The effect of local soil conditions was also reflected in the respiration.

In 1930, a covered wagon (Fig. 1) was made over into a portable laboratory to shield the apparatus. A bell having a volume of 2,100 cc and an area of 750 square cm was used.

Studies were made on the soils on the 4-year rotation plats on April 25 and 29. The land had been plowed in the fall and was harrowed a

week previous to the time of making the tests. Readings were made on the check plat on the 1400 range, at distances several feet apart, the respiration period being 15 minutes. Readings were made also on

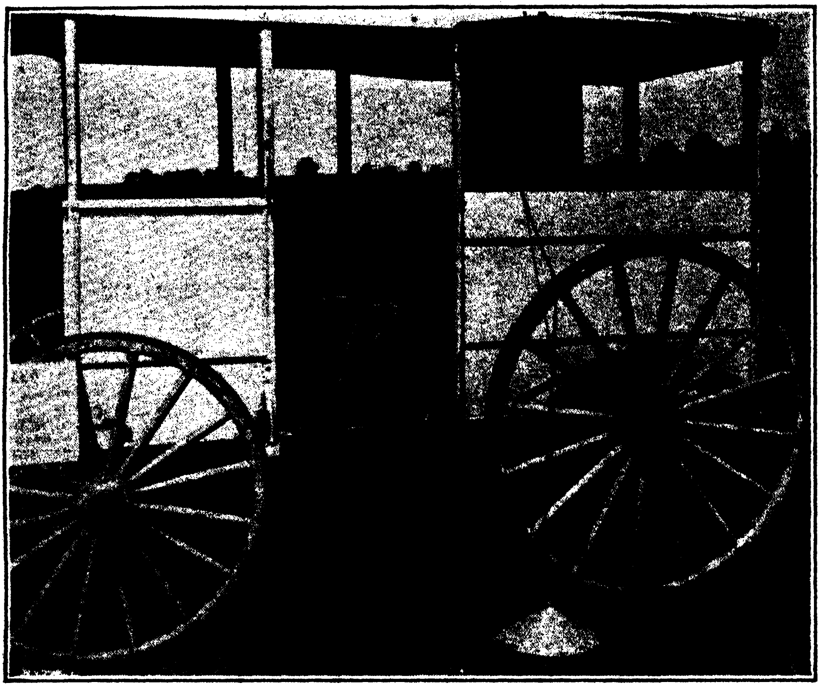

FIG. 1.—Covered wagon housing apparatus for determining the soil respiration.

this soil without removing the bell at 10-minute and 20-minute intervals. On the manured plat the readings were made in various locations at approximately the same length of respiration period. The results are given in Table 6.

TABLE 6.—*Soil respiration, 4-year rotation, 1930.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour	Date
1400	Check	0.7476	15	0.679	Apr. 25
1400	Check	0.1434	15	0.509	Apr. 25
1400	Check	0.3000	10	0.407	Apr. 29
1400	Check	1.0400	20	0.705	Apr. 29
1401	Manure	0.4033	12	0.456	Apr. 29
1401	Manure	0.5151	13	0.541	Apr. 29

The respiration from the soils on the continuous corn plats was determined on July 2. Several readings were made at different

periods. The results are presented in Table 7. The respiration was very low at this time, no doubt reflecting the effect of the drought. The results indicate that the length of the respiration period or time allowed for the accumulation of carbon dioxide in the bell is very important, and that the proper length of time will vary according to the amount of respiration.

TABLE 7.—*Soil respiration, continuous corn, 1930.*

Plat No.	Soil treatment	Increase in CO_2 in bell, %	Time, minutes	Grams CO_2 per sq. meter per hour
905	Check	0.0701	5	0.189
		0.0913	19	0.065
		0.1163	22	0.071
906	Manure	0.0393	5	0.107
		0.1712	15	0.155
		0.2395	18	0.181
907	Manure+lime	0.0596	11	0.074
		0.2010	24	0.119
908	Lime	0.0162	5	0.044
		0.0254	15	0.023
		0.0346	21	0.022
909	Check	0.0095	8	0.016
		0.0278	22	0.017

DISCUSSION AND SUMMARY

Lundegardh (7) has pointed out the fact that the concentration of carbon dioxide in the soil air is not a true measure of the rate of its production. The results secured in this investigation indicate that the soil respiration is not a simple diffusion of carbon dioxide, proportional to production, and it cannot, therefore, serve as an index of production. The respiration is also a function of the diffusion velocity and of the equilibrium of the gaseous-solution phase, for which there is no simple expression. Therefore, the respiration rate alone does not furnish sufficient data from which to measure the effect of treatment on carbon dioxide production in the soil.

Several unsuccessful attempts were made to determine the concentration of carbon dioxide in the soil air by means of a soil tube similar to the one used by Lundegardh (7). This tube is unsatisfactory when used with the Lundegardh volumetric apparatus, especially on heavy soils, because of the pressure necessary to obtain a sample for analysis. The volumetric apparatus is unsatisfactory when used in the field. This disadvantage was overcome in part by placing the apparatus in a covered wagon.

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CORRELATED INHERITANCE IN A CROSS BETWEEN DICKLOW X SEVIER WHEAT[1]

GEORGE STEWART[2]

This paper reports a study of the inheritance and the correlated inheritance of observed and measured characters in a cross between a pure line of Dicklow and a pure line 121 of Sevier. In view of the fact that the literature relative to the characters studied in this cross have been previously reviewed several times, all reference to literature is omitted here.

Dicklow is one of the leading spring wheats on irrigated farms in Utah and Idaho. The spikes are beaked, with short apical awns, and the glumes are white in color. The spikes are of intermediate density with a tendency to be clavate at the apex. The origin of Sevier is not

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by the Director, April 10, 1931. Received for publication April 14, 1931.

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determined, but it was first noted by the writer in 1918, in Sevier County, Utah. The spike is of intermediate density and fully awned. The glume color of Sevier is bronze. The contrasted plant characters of the two parents are presented in Table 1.

TABLE 1.—*Contrasted characters of Dicklow and Sevier 121.*

Parent	Characters that differ		
	Awns	Chaff	Spike density
Dicklow	Awns 2	White	Intermediate
Sevier 121	Awns 4	Bronze	Semi-dense

Sevier contains several pure lines which differ distinctly in spike density, of which line 121 is the most dense.

EXPERIMENTAL PROCEDURE

The cross between a pure line of Dicklow and a pure line of Sevier 121, genetic studies here reported, and preliminary yield tests were made on the Central Experimental Farm of the Utah Experiment Station at Logan, Utah, during the last few years. There were several F_2 families, and the most vigorous one of 490 plants was chosen to continue the experiment. Classification of each plant character which differed in the parents was noted in the F_2 plants.

Spike density was determined by the measurement of 10 rachis internodes from the central portion of the spike to avoid the extreme ends which are generally more variable. Awns were measured and also classified by observation, while chaff color was determined wholly by inspection.

Grain from each F_2 plant was used to seed an F_3 progeny row by spacing the kernels approximately 3 inches apart in the row, making from 25 to 50 plants in a 12-foot row. The rows were a foot apart.

After each tenth progeny row the parental rows were alternated with each other, making a total of 25 rows of Dicklow and 24 rows of Sevier.

The progenies were harvested when ripe by carefully pulling each plant and tying the plants of each row in a separate bundle. This material was studied in the laboratory during the winter months. Data were taken for height of plant by placing each plant on a properly ruled table board and measuring from the base of the culm to the base of the longest spike. The number of culms to the plant and the thickness of neck were obtained by measuring a typical culm for that character. Awn behavior was determined by observation. In most cases the length of awns was measured and recorded for correlation work. The awnless plants were not measured.

Spike density was determined for each F_3 plant by a measurement of 10 rachis internodes in the central portion of a typical spike.

The color of glumes was determined by inspection and listed as either bronze or white. Some plants, however, were difficult to classify as the color of the glumes was not clearly white or bronze.

EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

After the data were assembled and recorded for each individual plant, classifications and calculations were made. The mean of each F_3 progeny row was obtained for each character. The mean value thus obtained for each progeny was used as showing the true genotype of its parent F_2 plant. Spike density, awn inheritance, and color of glumes were classified into true-breeding or into segregating groups on the basis of the size of the coefficients of variability obtained.

Inheritance studies were made for spike density, color of glume, awn classes, number of culms, thickness of neck, and length of culm.

SPIKE DENSITY

The F_3 progenies were classified into one of three groups as calculated by the coefficients of variability as follows: (1) Those homozygous for dense spikes, (2) those heterozygous, and (3) those homozygous for lax spikes. In this cross the coefficient of variability did not give absolutely clear-cut groups as it has done in some crosses. For this reason the coefficients of variability were carefully observed and 18% arbitrarily chosen in deciding whether five or six doubtful progenies were homozygous or heterozygous. These doubtful progenies were too few to have influenced materially the closeness of fit studies. Homozygous progenies had, with the few exceptions noted, a coefficient of variability range from 6 to 15%, while the heterozygous progenies ranged from 25 to 40%.

The Dicklow and Sevier parents showed mean coefficients of variability of 8.48 and 10.7%, respectively.

The mean coefficient of variability for the homozygous dense progenies was 11.6% and ranged from 1 to 18%. The homozygous lax progenies ranged from 4.65 to 20.4%, with a mean of 10.5%, while the heterozygous progenies ranged from around 18 to 51%, with a mean of 30.66%. Table 2 shows the distribution of the parental rows and the 459 F_3 progenies according to density of spike and the coefficient of variability.

On the basis of 18% (C.V.) as separating true-breeding from segregating progenies, 117 were homozygous dense, 221 were heterozygous, and 121 progenies homozygous for lax spikes. A one-factor difference was suggested. In Table 3 the goodness of fit compared

TABLE 2.—*Frequency distribution of the Dicklow and Sevier parents and of F_3 progenies arranged into classes according to the mean spike density and according to the coefficients of variability (C.V.) classes of the individual rows of parents of the F_3 hybrid progenies, family (23a–2), grown at Logan, Utah.*

Parent or progeny	Spike density classes, length of 10 spike internodes (mm)															C.V. classes	Total number of individuals
	18	21	24	27	30	33	36	39	42	45	48	51	54	57	Total		
Dicklow	–	–	–	–	–	–	–	–	5	10	–	–	–	–	15	7	25
	–	–	–	–	–	–	–	–	–	7	–	–	–	–	7	10	
	–	–	–	–	–	–	–	–	1	1	–	–	–	–	2	13	
	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	16	
															Mean	8.48	
Sevier	–	–	7	2	2	–	–	–	–	–	–	–	–	–	11	7	25
	–	–	4	3	–	–	–	–	–	–	–	–	–	–	7	10	
	–	–	2	2	–	–	–	–	–	–	–	–	–	–	5	13	
	–	–	1	1	–	–	–	–	–	–	–	–	–	–	2	16	
															Mean	10.7	
Homozygous dense and homozygous lax	–	5	7	2	1	–	–	2	1	5	9	2	3	–	37	6	459
	4	9	12	6	2	1	1	3	8	18	13	7	–	1	84	9	
	3	16	10	5	3	–	1	2	5	8	13	4	–	–	70	12	
	–	6	8	8	–	1	1	1	2	3	4	2	1	–	37	15	
	–	4	2	4	1	1	1	1	3	–	1	–	–	–	18	18	
	–	1	2	2	–	–	1	–	–	–	–	1	–	–	7	21	
	–	–	1	4	7	8	1	–	2	–	–	–	–	–	23	24	
Heterozygous	–	–	2	10	17	4	6	2	3	–	–	–	–	–	44	27	
	–	–	4	6	12	9	2	2	1	–	–	–	–	–	48	30	
	–	–	2	6	11	11	5	4	–	–	–	–	–	–	39	33	
	–	–	1	4	7	8	6	1	1	–	–	–	–	–	28	36	
	–	–	–	2	6	5	1	1	–	–	–	–	–	–	15	39	
	–	–	–	1	1	2	–	–	1	–	–	–	–	–	5	42	
	–	–	–	1	1	–	–	–	–	–	–	–	–	–	2	45	
	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1	48	
	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1	51	
															Mean	20.4	

to a 1:2:1 ratio is presented. With the suggested figure as a basis of classifying spike density $X^2 = .8131$ and $P = .6852$, which means that 68 times out of a 100 a worse fit would be expected due to chance alone.

TABLE 3.—*Closeness of fit between observed and calculated number of progenies when spike density is explained on a 1:2:1 ratio, Logan, Utah.*

Spike density class	Calculated	Observed (O)	O–C	$(O–C)^2$	$\frac{(O–C)^2}{C}$
Homozygous dense	115	117	2	4	.0348
Heterozygous	230	221	9	81	.3522
Homozygous lax	115	121	7	49	.4261

$X^2 = .8131 \quad P = 0.6852$

Both parents were recovered with respect to spike density. There seemed, however, to be some tendency for transgressive segregation in both directions, that is, there was a group of true-breeding progenies distinctly more dense than the dense parent and a group distinctly more lax than the lax parent. These data are summarized in Table 4.

TABLE 4.—*Mean spike density of the two parents and of the dense and lax homozygous groups and of apparently transgressive progeny groups, together with the deviation of the progeny groups from the comparable parent and its ratio to the probable error of the difference.*

Parent or strains	Mean for entire group	Deviation from comparable parent mean	Dev. P.E.
Sevier 121	25.38±.38	—	—
Homozygous dense (all progenies)	23.35±.16	2.03± .41	4.9
Homozygous dense (12 most dense progenies)	19.91±.40	5.47± .55	9.9
Dicklow	44.13±.52	—	—
Homozygous lax (all progenies)	46.43±.32	2.30± .61	3.8
Homozygous lax (14 most lax progenies)	51.89±.86	7.76±1.00	7.8

COLOR OF GLUME

The Dicklow parent has white glumes, while the Sevier 121 parent has glumes of intermediate bronze. The bronze glumes were dominant to white glumes shown by all F_1 plants having bronze chaff but segregating in F_2 generation. The F_3 progenies indicate that 143 F_2 plants were homozygous for bronze, 205 heterozygous, and 112 progenies homozygous for white glumes. A one-factor difference was suggested to explain the inheritance of glume color. Table 5 shows the goodness of fit when compared to the suggested 1:2:1 ratio. In this table $X^2 = 9.964$ and $P = .0071$, which is a poor fit. It has already been noted that difficulty was encountered in classifying plants for glume color.

TABLE 5.—*Closeness of fit between observed and calculated number of progenies when glume color is explained on a 1:2:1 ratio.*

Glume color class	Calculated (C)	Observed (O)	(O–C)	$(O-C)^2$	$\frac{(O-C)^2}{C}$
Homozygous bronze	115	143	28	824	7.165
Segregating	230	205	25	625	2.717
Homozygous white	115	112	3	9	0.0782

$X^2 = 9.964$ $P = 0.0071$

AWN CLASSES

The behavior of awn inheritance has varied a great deal in the many crosses reported in various reviews of literature. Often simple

ratios were obtained, and occasionally some rather complicated results were obtained. It has been generally conceded that two or more factors are required properly to explain awn behavior. In this study Dicklow was awn-tipped or beaked and Sevier fully awned. For convenience, Dicklow is said to have had awns 2, while Sevier had awns 4. The F_3 progeny data show 111 progenies homozygous for awns 2, 234 heterozygous, and 115 progenies homozgyous for awns 4. These figures suggest the simple 1:2:1 ratio and when compared (Table 6) in a goodness of fit study $X^2=.0522$ and $P=.9803$ which indicates that 98 times out of 100 a worse fit would be expected due to chance alone. Both parental types were recovered in the homozygous progenies, and a one-factor difference satisfactorily explains the awn behavior in this cross.

TABLE 6.—*Closeness of fit between observed and calculated numbers of progenies when awn classes are explained on the basis of a 1:2:1 ratio.*

Awn class	Calculated (C)	Observed (O)	(O–C)	$(O-C)^2$	$\frac{(O-C)^2}{C}$
Homozygous 2	115	111	4	16	.0348
Heterozygous	230	234	4	16	.0174
Homozygous 4	115	115	0	0	.000
				$X^2=.0522$	$P=.9803$

NUMBER OF CULMS

Both parents were essentially alike for the number of culms, Dicklow being represented by a mean of 7.5 culms and Sevier by a mean of 7.4 culms. No segregation would be expected nor could be observed in the data taken. The mean number of culms for all the progeny rows was 7.24. Data on the number of culms were taken primarily for correlation studies to be presented later. Table 7 shows the distribution of parental rows and F_3 progenies for the number of culms and their coefficients of variability.

The Dicklow parent had a coefficient of variability (C.V.) range of from 28 to 55%, with a mean of 39.5%. Sevier ranged from 26.9 to 64.6%, with a mean of 43.2, while the F_3 progenies ranged from 12 to 102%, with a mean of 39.66.

THICKNESS OF NECK

Careful measurements were made for thickness of neck by measuring with calipers the diameter of the culm just below the spike of a representative culm from each plant of the parental and of the progeny rows. The Dicklow parent showed a range from 2.4 to 2.8 mm, with a mean of 2.6 mm for thickness of neck. Sevier ranged

TABLE 7.—*Parental rows and F_3 progenies arranged according to numbers of culm classes and according to coefficients of variability (C.V.) classes.*

Parent or progeny	Number of culm classes													Total	C.V. classes	Total number
	3	4	5	6	7	8	9	10	11	12	13	14	15			
	–	–	–	–	1	1	–	–	–	–	–	–	–	1	25	
Dicklow...	–	–	–	4	3	1	–	1	–	–	–	–	–	9	35	25
	–	–	–	3	4	4	–	1	–	–	–	–	–	12	45	
	–	–	–	1	–	–	–	1	–	–	–	–	–	2	55	
	–															
														Mean	39.5	
	–	–	–	–	–	–	–	1	–	–	–	–	–	1	25	
	–	–	1	1	5	2	–	–	–	–	–	–	–	9	35	24
Sevier.....	–	–	1	2	1	2	–	1	–	–	–	–	–	7	45	
	–	–	1	3	–	1	–	–	–	–	–	–	–	5	55	
	–	–	–	–	–	1	–	1	–	–	–	–	–	2	65	
														Mean	43.2	
	–	–	–	2	1	2	1	1	–	–	–	–	–	7	15	
	–	1	4	10	20	13	6	2	–	–	–	–	–	56	25	
	–	4	16	46	42	33	18	9	4	–	1	1	1	175	35	
	–	6	16	29	56	22	14	7	–	1	1	–	–	152	45	459
F_3........	1	1	6	11	9	10	8	5	2	–	–	–	–	53	55	
	–	–	3	2	3	1	2	1	–	–	–	–	–	12	65	
	–	–	–	2	–	–	–	–	–	–	–	–	–	2	75	
	–	–	–	–	–	–	–	–	–	–	–	–	–	—	85	
	–	–	–	–	–	–	–	–	–	–	–	–	–	—	95	
	–	–	–	–	–	2	–	–	–	–	–	–	–	2	105	
														Mean	39.66	

from 2.1 to 2.6 mm, with a mean of 2.4 mm. The 459 F_3 progenies ranged from 0.7 to 3.4 mm, with a mean of 2.65 mm. As shown by their means, the coefficients of variability were 9.7% for Dicklow with a range of from 5 to 14%, and 9.2% for Sevier, with a range from 3 to 24%. The mean for the F_3 progenies was 10.8%, with a corresponding range of 1 to 41%. Greater variability is shown in the progenies than in the parent rows. Table 8 shows the distribution of the parental rows and of the F_3 progenies with their corresponding coefficients of variability.

HEIGHT OF PLANT

The mean culm length of the Dicklow parent was 90.2 cm, with a range from 79.6 to 104.4 cm. The Sevier parent ranged from 82 to 121.5 cm, with a mean height of 105.2 cm. This cross, Dicklow x Sevier, segregated in the F_2 for dwarfs. Since the genetic data of the dwarfs of this cross, along with some other crosses, form part of another study, they are not presented here. However, two tables have been arranged for height of plant, one including all plants and the other composed of only the normal plants of this cross.

TABLE 8.—*Frequency distribution of the rows of Dicklow and Sevier parents and of F_3 progenies arranged into classes according to the mean thickness of neck and according to the coefficients of variability classes of the individual rows.*

Parent or progeny	Thickness of neck classes (mm)									Total	C.V. classes	Total number indivi-duals
	1	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.4			
	–	–	–	–	–	–	–	–	–	..	4	
	–	–	–	–	–	1	–	–	–	1	6	
Dicklow...	–	–	–	–	–	4	1	–	–	5	8	25
	–	–	–	–	–	8	3	–	–	11	10	
	–	–	–	–	–	3	4	–	–	7	12	
	–	–	–	–	–	1	–	–	–	1	14	
										Mean	9.7	
	–	–	–	–	–	1	–	–	–	1	4	
	–	–	–	–	–	2	–	–	–	2	6	
	–	–	–	–	2	8	–	–	–	10	8	
	–	–	–	–	3	4	–	–	–	7	10	
	–	–	–	–	–	1	–	–	–	1	12	24
Sevier	–	–	–	–	1	1	–	–	–	2	14	
	–	–	–	–	–	–	–	–	–	—	16	
	–	–	–	–	–	–	–	–	–	—	18	
	–	–	–	–	–	–	–	–	–	—	20	
	–	–	–	–	–	–	–	–	–	—	22	
	–	–	–	–	–	1	–	–	–	1	24	
										Mean	9.2	
	–	–	–	–	–	2	1	–	–	3	2	
	–	–	–	–	–	4	3	1	–	8	4	
	–	–	–	–	1	10	9	3	–	23	6	
	–	–	–	–	5	55	35	10	1	106	8	
	–	–	–	–	9	51	64	12	1	137	10	
F_3........	–	–	–	1	13	37	42	10	1	104	12	
	–	–	–	–	3	22	19	3	–	47	14	
	–	–	–	–	1	2	9	2	–	14	16	
	–	–	–	–	–	1	1	1	–	3	18	
	–	–	–	–	–	3	–	–	–	3	20	
	–	–	–	–	1	1	–	–	–	2	22	
	–	–	–	–	–	–	–	–	–	—	24	
	–	–	–	–	–	–	1	–	–	1	26	459
	–	–	–	–	–	–	–	–	–	—	28	
	1	–	–	–	–	–	–	–	–	1	30	
	–	–	–	–	–	1	–	–	–	1	32	
	–	–	–	–	–	–	1	–	–	1	34	
	–	–	–	–	–	1	–	–	–	1	36	
	1	–	–	–	–	–	–	1	–	2	38	
	–	–	–	–	–	1	1	–	–	2	40	
										Mean	10.8	

When both tall and dwarf plants were included, the range in height was from 25 to 120.9 cm. The coefficients of variability of Dicklow ranged from 3.2 to 11.5%, with a mean of 7.5%. Sevier ranged from 3.7 to 10.3%, with a mean of 6.9%. The F_3 progenies, including dwarfs, ranged from 3 to 71%, with a mean of 20.3%. Table 9 shows the distribution of the parental rows and the F_3 progenies with the

TABLE 9.—*Parental rows and F_3 progenies arranged according to means of culm length and according to coefficients of variability (C.V.), including all dwarfs as they appeared in cross (23a–2).*

Parent or progeny	Class																					Total	C.V. class	Total individuals
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125			
Dicklow	—	—	—	—	—	—	—	—	—	—	—	—	—	3	2	1	—	—	—	—	—	6	4	25
	—	—	—	—	—	—	—	—	—	—	—	1	5	7	—	—	1	—	—	—	—	14	7	
	—	—	—	—	—	—	—	—	—	—	—	2	1	2	—	—	—	—	—	—	—	5	10	
																						Mean	7.5	
Sevier	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	2	1	—	6	4	24
	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	5	3	3	1	—	—	14	7	
	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	1	—	1	—	—	—	4	10	
																						Mean	6.9	
F_1	—	—	—	—	—	—	—	—	—	—	1	2	1	4	6	6	5	2	—	—	—	27	4	486
	—	—	—	—	—	—	—	—	—	—	3	3	16	18	34	26	11	2	1	—	—	114	7	
	—	1	—	—	—	—	—	—	—	3	1	6	13	18	25	4	2	—	—	—	—	73	10	
	—	1	2	1	—	—	—	—	—	2	—	3	6	8	2	2	—	—	—	—	—	27	13	
	—	—	1	1	1	—	—	—	—	2	2	2	2	4	2	—	3	1	—	—	—	21	16	
	1	—	1	2	1	—	—	2	1	1	3	2	—	—	1	—	—	1	—	—	—	16	19	
	—	1	3	1	—	—	—	—	—	1	2	2	3	5	2	1	—	—	—	—	—	21	22	
	—	1	—	—	3	1	—	—	—	—	1	11	4	1	4	—	—	—	—	—	—	26	25	
	—	—	1	—	1	—	1	—	2	1	5	7	6	2	1	—	—	—	—	—	—	27	28	
	—	—	—	—	—	1	1	—	2	2	5	9	8	4	3	—	—	—	—	—	—	35	31	
	—	—	1	1	1	—	—	1	1	4	6	7	5	1	—	1	—	—	—	—	—	29	34	
	—	—	1	—	1	—	2	—	4	2	3	3	1	—	—	—	—	—	—	—	—	17	37	
	—	—	—	—	—	2	—	1	1	6	3	3	1	—	—	—	—	—	—	—	—	17	40	
	—	—	—	—	1	1	—	2	1	1	3	—	1	1	—	—	—	—	—	—	—	11	43	
	—	—	—	2	—	1	—	1	2	2	1	—	—	—	—	—	—	—	—	—	—	9	46	
	—	—	—	—	2	—	—	2	1	1	—	—	—	—	—	—	—	—	—	—	—	6	49	
	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2	52	
	—	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	2	55	
	—	—	1	1	—	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	58	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	61	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64	
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	67	
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	70	
																						Mean	20.3	

dwarfs included. In Table 9 the true-breeding dwarfs are separated from the other groups, but the homozygous tall progenies overlap with the heterozygous group.

In Table 10 only the tall plants of the segregating progenies are considered and all homozygous dwarfs are omitted. The range in height is from 59 to 117 cm, with a mean of 94.1 cm. The coefficients of variability showed a range from 3.4 to 24%, with a mean of 9.2%. It is evident from the two tables that the dwarf population caused the unusually wide variability for height of plant over the parental rows found in Table 9, and that when only the tall plants are considered, as shown in Table 10, the progenies vary little more than do the parental types.

TABLE 10.—*Parental rows and F_3 progenies arranged according to means of culm length and according to coefficients of variability (C.V.) classes, cross (23a–2), dwarfs excluded, length of longest culm (cm).*

Parent or progeny	Class													Total	C.V. class	Total individuals
	60	65	70	75	80	85	90	95	100	105	110	115	120			
	-	-	-	-	-	-	3	2	1	-	-	-	-	6	4	
Dicklow	-	-	-	-	1	5	7	-	-	1	-	-	-	14	7	25
	-	-	-	-	2	1	2	-	-	-	-	-	-	5	10	
														Mean	7.5	
	-	-	-	-	-	-	-	-	1	1	1	2	1	6	4	
Sevier	-	-	-	-	-	-	1	1	5	3	3	1	-	14	7	24
	-	-	-	-	1	-	1	-	1	-	1	-	-	4	10	
														Mean	6.9	
F_3	-	-	-	1	5	6	10	15	10	5	6	1	-	59	4	
	-	-	-	5	7	29	48	58	35	15	3	1	-	201	7	
	-	-	2	4	21	25	34	22	12	6	1	-	-	127	10	
	-	1	-	4	8	13	7	8	2	-	-	-	1	44	13	459
	-	-	3	2	3	3	3	3	-	-	-	-	-	17	16	
	1	1	-	1	2	2	1	-	-	-	-	-	-	8	19	
	-	-	-	-	-	1	-	-	-	-	-	-	-	1	22	
	-	-	1	-	1	-	-	-	-	-	-	-	-	2	25	
														Mean	9.2	

CORRELATION STUDIES

For those characters which could be measured or counted, correlation studies were made, and the following correlations studied: (1) Culm length and number of culms, (2) culm length and spike density, (3) culm length and awn length, (4) culm length and thickness of neck, (5) number of culms and spike density, (6) number of culms and awn length, (7) number of culms and thickness of neck, (8) spike

density and awn length, (9) spike density and thickness of neck, and (10) awn length and thickness of neck. Table 11 gives a summary of the correlation studies made for the above combinations.

TABLE 11.—*Correlation coefficients (r), correlation ratios (n), their respective probable errors (P.E.), and Blakeman's test of linearity for various pairs of plant characters.*

Characters correlated	r±P.E.	n±P.E.	Blakeman's test
Height of plant x number of culms	.04515±.03144	——	—
Height of plant x spike density	.1711 ±.03058	——	—
Height of plant x awn length	.0818 ±.03602	——	—
Height of plant x thickness of neck	.0123 ±.03144	.257 ±.02937	4.367
Number of culms x spike density	.0673 ±.03134	——	—
Number of culms x awn length	.1117 ±.0357	——	—
Number of culms x thickness of neck	.2349 ±.02974	.29902±.02867	3.036
Number of culms x thickness of neck (extremes omitted)	.2198 ±.03014	.27885±.02922	2.786
Spike density x awn length	.2322 ±.03425	——	—
Spike density x awn length for awns 4	.7121 ±.03141	——	—
Spike density x thickness of neck	.0287 ±.03145	.14695±.0308	2.34
Awn length x thickness of neck	.1879 ±.03483	.3087 ±.03265	3.592

The correlation coefficient (r) and the probable error (P.E.) were calculated for each of the contrasted pairs of characters. The correlation ratio (η) and Blakeman's test for linearity were calculated for cases in which r was low but in which it was thought there might be a possibility of non-linear correlation.

When height of plant and number of culms were correlated, the value of r was $+.0452\pm.0314$, which is not significant. In the correlation of length of culm and spike density $r=+.1711\pm.0306$. This correlation was too slight to be considered of importance. Correlation between culm length and awn length was $r=+.0818\pm.0360$ and is also not significant. When culm length and thickness of neck were correlated $r=+.0123$ and $\eta=.257$. When put through Blakeman's test, the difference between η^2 and r^2 was 4.37 times the probable error which indicates that the regression is non-linear. The number of culms and spike density also showed a low value for r, *viz.*, $.0673\pm.0313$, which is not significant. In the correlation number of culms and awn length $r=.1117\pm.0357$.

The number of culms and thickness of neck approached a positive correlation value. In this case $r=+.2349\pm.0297$. The value of $\eta=.299\pm.0287$. In this correlation six plants were widely variant from the bulk of the population. They were omitted and the correlation reworked. In this case, r was $+.2198\pm.0301$ and η was $.2789\pm.0292$, both less than when the entire population was included.

Spike density and awn length approached a positive correlation, *viz.*, $r = +.2323 \pm .0343$. To test this correlation further, all the fully-awned progenies were considered, and in that case $r = +.7121 \pm .0314$.

When spike density and thickness of neck were correlated, the value of r was $+.0287 \pm .0315$ and $\eta = .1469 \pm .0308$. No correlation was suggested.

When awn length and thickness of neck were correlated, $r = +.1879 \pm .03483$ and $\eta = .3087 \pm .03265$. Blakeman's test gave a difference between η^2 and r^2 of 3.59 times the probable error.

SUMMARY

In the cross of Dicklow x Sevier wheats the characters studied were measured or counted. Spike density was studied by careful measurement of 10 rachis internodes on a leading spike from each plant. The coefficient of variability was obtained for each progeny and parent row and used as the basis of classifying the breeding behavior of the F_2 plants. A 1:2:1 ratio was suggested, and when compared to a goodness of fit $X^2 = .8131$ and $P = .6852$. Both parental types were recovered in the homozygous progenies.

In the F_3 progenies 143 were homozygous for bronze, 205 heterozygous, and 112 progenies homozygous for white glumes. A one-factor difference was again suggested, and the goodness of fit compared to a 1:2:1 ratio is represented by $X^2 = 9.964$ and $P = .0071$, which is a poor fit. The peculiar light bronze cast on some progenies and some weather stain caused difficulty in this classification.

Dicklow is characterized by short awn tips, which were classified as awns 2, while the Sevier parent, fully-awned, is designated as having awns 4. The F_3 progenies showed clear-cut segregation into three groups, *viz.*, 111 progenies were homozygous for awns 2, 234 progenies heterozygous, and 115 homozygous for awns 4. A one-factor difference explains the results in this cross and when compared to a 1:2:1 ratio, $P = .9803$.

Both parents were essentially alike for the number of culms, and the 459 F_3 progenies studied showed about the same range and mean.

The Dicklow parent showed a mean thickness of neck of 2.6 mm, Sevier a mean of 2.4 mm, and the F_3 progenies a mean of 2.65 mm. No segregation could thus be observed.

The height of plant was studied with the dwarfs included and again with only the tall plants. When the dwarfs were included, unusually high variability occurred compared with the parental rows and with the study of only the tall plants of the progenies. Segregation of the homozygous dwarfs is clearly set apart in Table 9 as are also the homozygous tall plants.

Correlation studies were made for all possible combinations of characters on which data were obtained. The only important positive correlation found was for spike density and awn length. This was merely suggestive, *viz.*, $r=.2322$, when the entire population was considered; but when the 112 homozygous progenies for awns 4 were studied, a correlation of $+.7121\pm.03141$ was found.

THE ADAPTATION OF CORN TO UPLAND AND BOTTOM LAND SOILS[1]

T. H. Goodding and T. A. Kiesselbach[2]

The extent to which corn undergoes heritable changes in response to differences in soil conditions is a phase of the problem of adaptation concerning which there have been relatively few data available. It has come to be well recognized that the vegetative characteristics of corn most suitable in various regions differ greatly in relation to the prevailing climatic conditions.

The pronounced effects of such regional adaptation of corn to climate in Nebraska have been investigated and reported by Kiesselbach and Keim (2).[3] No significant histological or physiological differences were noted. The heritable effects were found to be largely restricted to vegetative size and earliness of maturity as influenced by rainfall, temperature, and length of growing season. These characters are associated with the economy of water usage, utilization of the full growing season, and maturity before frost.

But the question, "Does it make a material difference under what soil conditions the seed of open-pollinated varieties has been produced?" has remained largely unanswered. The investigations herein reported have been conducted for the purpose of obtaining some additional information bearing on this question.

It would seem desirable to conduct a study of this kind in such manner as to eliminate as far as possible other influencing factors aside from soil productivity itself. This would often preclude the possibility of dividing a state into a number of soil regions and ignoring the effects of associated climatic differences. Thus it would not be possible in Nebraska to compare corn types native to the Sand hills region of northwestern Nebraska with types from the Loess soils of south eastern Nebraska and attribute the plant differences to the soil factors.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as paper No. 101, Journal Series. Received for publication April 14, 1931.

[2]Agronomists.

[3]Reference by number is to "Literature Cited," p. 937.

These studies consisted primarily of a detailed comparison of the plant characters and yield of commercial varieties of corn which were native to upland and bottom land soils,[4] respectively, within a given locality. It was believed that representative results might be obtained by assembling a number of such sorts from each of the two conditions and growing them comparably within the same field. Through general experience with these soils, the uplands were known to be less productive than the bottom lands, due to lower soil fertility. In seasons of favorable rainfall these bottom land soils have a capacity, in general, to produce about double the corn yield of the upland soils. Soil moisture differences are not believed to have been a material factor since the land was in no case subject to subirrigation, overflow, or undue runoff. The two soil conditions under contrast must not be thought of as abrupt changes within a single farm, but rather as represented by either upland or bottom land farms of a fairly level topography.

LITERATURE REVIEW

Williams and Welton (5) have concluded that "the conditions of growth are not important factors in the selection of seed corn." Two strains of corn known as "Rich" and "Poverty" were developed from the same origin by 6 years of continuous culture on adjoining heavily fertilized and unfertilized plats, respectively. Each year seed selected from these two sources was grown comparably under uniformly good conditions. As an average for the 6-year period, 1907–12, the rich land strain yielded 62.26 bushels of shelled grain and the poverty strain 62.20 bushels per acre.

Mooers (3) concluded from regional varietal tests in Tennessee that varieties may differ strikingly in their relative suitability for rich and poor land areas of the state. No consideration was given to the rôle played by climatic differences associated with these regional soil areas.

Hoffer (1) has indicated that selfed lines of corn differ in their response to soil deficiencies.

[4]These soils were located in three eastern Nebraska counties and the soil types involved were as follows: (a) In Lancaster County, the upland and bottom land soils were, respectively, Carrington silt loam and Wabash silt loam. (b) The upland soil in Washington County consisted of Knox silt loam, while on the bottom lands both Cass silt loam and Sarpy very fine sandy loam occurred. (c) In Nance County, two localities were concerned. North of the Loup river the upland soil was Marshall silt loam which had been depleted by erosion and the bottom land soil was Wakeshaw silt loam. South of the river the corresponding soils were Valentine sand and O'Neill fine sandy loam.

TABLE 1.—*Summary of tests comparing plant characters and yield of corn native to Nebraska, crop grown at Nebraska*

Source of seed and year tested	Date tasseling	Date ripe	Suckers per 100 plants	Barren plants %	2-eared stalks %	Lodged stalks %	Shrinkage of ear corn %	Shelling %	Yield per acre, bu.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			Upland						
Nance Co., 1921*	July 20	Sept. 5	6	5	0	75	1.0	88.5	63.4
Nance Co., 1921†	July 21	Sept. 5	0	4	0	82	4.6	83.2	56.4
Washington Co., 1921	July 24	Sept. 4	1	7	1	77	2.1	81.4	49.8
Lancaster Co., 1921	July 23	Sept. 4	3	6	0	83	2.4	85.7	62.0
Nance Co., 1922†	Aug. 2	Sept. 13	4	16	0	16	2.0	83.7	38.9
Washington Co., 1922	Aug. 4	Sept. 11	4	20	0	16	2.0	85.1	33.3
Lancaster Co., 1922	Aug. 3	Sept. 11	5	17	0	14	1.8	82.3	37.0
Average	July 27	Sept. 8	3	11	0	52	2.3	84.3	48.7
			Bottom Land						
Nance Co., 1921	July 21	Sept. 5	3	5	0	85	1.6	85.1	57.4
Nance Co., 1921	July 20	Sept. 5	2	4	0	80	4.6	84.0	56.2
Washington Co., 1921	July 24	Sept. 3	1	7	1	79	1.3	84.3	51.6
Lancaster Co., 1921	July 23	Sept. 6	2	6	0	77	2.1	84.2	59.7
Nance Co., 1922	Aug. 2	Sept. 11	6	16	0	15	2.1	84.5	37.7
Washington Co., 1922	Aug. 4	Sept. 11	4	20	0	12	1.9	85.2	35.3
Lancaster Co., 1922	Aug. 3	Sept. 12	5	16	0	15	1.9	85.1	37.7
Average	July 27	Sept. 8	3	11	0	52	2.2	84.7	48.0
			Average Relative Results, %						
Upland	—	—	100	100	100	100	100	100	100
Bottom land	—	—	100	100	100	100	96	100	99

*Corn secured from heavy soil north of Loup River.
†Corn secured from light soil south of Loup River.

Stadler and Helm (4) have listed the varieties of corn best suited respectively to the upland and bottom land soils of Missouri as follows: Northern upland soils, Reid and Leaming; central upland soils, Boone Co. White, St. Charles White, and Commercial White; southeast upland, St. Charles White; and north and south bottom lands, Boone Co. White.

EXPERIMENTAL

The present investigations may be grouped under four main tests, varying from 1 to 5 years in duration. All were comparisons of upland and bottom land corn grown in eastern Nebraska. In each test, the seed stocks under direct comparison came from within a radius of 10 miles of each other and had therefore in the past been subject to rather similar climatic conditions. Only seed was used which had been grown for 5 years or longer on the farm from which it was obtained. The upland and bottom land samples had therefore had time to undergo adaptive changes, should such changes occur. While corn types grown by individual farmers differed somewhat, it is believed that the average of a number of varieties from each locality should give fairly representative results. The data should indicate whether

upland and bottom land farms in Nance, Washington, and Lancaster Counties, Experiment Station, 1921 and 1922.

Individual plant measurements							Leaf area per lb. grain, sq. in§	Ratio grain to whole plant§	Ear measurements, inches		Kernel measurements, inches	
Height, in.		Leaf area, sq. in.	No. of leaves	Weight per plant, lbs.								
Stalk	Ear			Stover‡	Grain	Total			Length	Diameter	Length	Width
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
						Upland						
104	46	1,003	15	0.36	0.38	0.74	2,639	0.514	6.5	1.8	0.52	0.32
103	48	1,077	16	0.38	0.38	0.76	2,834	0.500	6.4	1.9	0.46	0.29
118	55	1,129	17	0.49	0.34	0.83	3,321	0.410	6.6	1.7	0.47	0.26
111	55	1,136	15	0.39	0.34	0.73	3,341	0.466	6.9	1.6	0.47	0.30
109	44	1,131	16	0.33	0.20	0.53	5,655	0.377	5.2	1.7	0.43	0.31
115	52	1,287	18	0.39	0.21	0.60	6,128	0.350	6.1	1.7	0.44	0.28
110	47	1,172	16	0.36	0.22	0.58	5,327	0.379	5.8	1.8	0.44	0.31
110	50	1,134	16	0.39	0.30	0.69	4,178	0.428	6.2	1.7	0.46	0.30
						Bottom Land						
106	47	1,071	16	0.37	0.37	0.74	2,895	0.500	6.8	1.9	0.49	0.32
105	48	1,086	16	0.40	0.39	0.79	2,785	0.494	6.5	1.9	0.50	0.30
114	52	1,148	16	0.40	0.35	0.75	3,280	0.467	6.8	1.7	0.48	0.27
117	55	1,106	16	0.43	0.35	0.78	3,160	0.449	6.4	1.5	0.48	0.26
103	46	1,157	16	0.34	0.20	0.54	5,785	0.370	5.2	1.7	0.46	0.32
113	51	1,219	17	0.37	0.22	0.59	5,541	0.373	6.1	1.7	0.44	0.29
113	50	1,259	17	0.40	0.22	0.62	5,723	0.355	6.0	1.8	0.45	0.29
110	50	1,149	16	0.39	0.30	0.69	4,167	0.430	6.3	1.7	0.47	0.29
						Average Relative Results, %						
100	100	100	100	100	100	100	100	100	100	100	100	100
100	100	101	100	100	100	101	100	100	102	100	102	97

‡Stover includes cob.
§The data in columns 18 and 19 are averages of ratios.

the corn grown by farmers on the upland soils differs inherently from that being grown on the bottom lands.

In any one test, the samples of the two groups under comparison were grown alternatingly in either one-row or three-row triplicated field plats. The rows usually contained 60 hills of 3 plants each. The seed was planted at a double rate followed by thinning to a normal stand. Detailed plant and ear measurements were made on 10 consecutive plants in each plat, while the acre yields were determined from the entire plat. Leaf-area measurements were made by Montgomery's formula, *viz.*, taking three-fourths of the product of the length X the maximum width of the individual leaves and adding together these products for the total leaf area.

SEED SAMPLES FROM NANCE, LANCASTER, AND WASHINGTON COUNTIES TESTED INDIVIDUALLY, 1921–22

During the 2 years, 1921 and 1922, seed native to upland and bottom land conditions in Nance, Lancaster, and Washington Counties was compared by planting comparatively on the experiment station farm at Lincoln. Five varieties were included to represent

TABLE 2.—*Comparison of plant characters and yield of corn native to 10 upland and ment Station during*

Source of seed	Date tasseling	Date ripe	Suckers per 100 plants	Barren plants %	2-eared stalks %	Lodged stalks %	Shrinkage of ear corn %	Shelling %	Yield per acre, bu.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			Upland						
H. P. Loos	Aug. 2	Sept. 19	8	28	1	16	7.0	82.2	36.6
A. C. Hass	Aug. 2	Sept. 19	6	27	1	16	7.9	82.5	38.0
E. C. Lange	Aug. 2	Sept. 19	8	32	0	15	9.2	83.0	40.4
T. J. Shabel	Aug. 2	Sept. 19	5	32	1	22	8.2	83.9	40.0
Wm. Mueller	Aug. 3	Sept. 19	8	33	1	16	8.3	83.4	40.5
Carl Lange	Aug. 3	Sept. 19	14	32	1	16	10.3	83.2	41.8
E. Heidtbrink	Aug. 3	Sept. 20	12	33	1	12	10.0	82.9	42.2
E. T. Brauer	Aug. 1	Sept. 19	4	31	0	18	6.5	83.9	46.2
C. Busboom	Aug. 2	Sept. 20	7	29	1	19	7.5	83.0	42.1
Casper Lange	Aug. 2	Sept. 19	9	32	2	20	10.0	83.3	41.9
Average	Aug. 2	Sept. 19	8	31	1	17	8.5	83.1	40.9
			Bottom Land						
W. E. King	Aug. 2	Sept. 19	8	30	1	14	7.6	83.0	41.7
S. D. Breck	Aug. 2	Sept. 20	5	31	1	16	10.3	82.5	38.7
Louis Funk	Aug. 3	Sept. 20	5	30	2	17	9.8	83.0	39.7
A. Nelson	Aug. 2	Sept. 20	6	31	2	17	7.3	82.8	39.0
Chas. Schnirl	Aug. 3	Sept. 19	8	32	1	19	8.4	83.3	41.0
A. Brown	Aug. 2	Sept. 19	6	32	1	16	6.6	83.2	40.0
W. B. Gregg	Aug. 2	Sept. 19	5	30	0	17	10.5	82.9	39.1
J. E. Harrison	Aug. 2	Sept. 19	9	33	1	15	8.9	83.1	40.6
F. Flader	Aug. 3	Sept. 19	4	31	0	21	7.2	83.7	41.6
M. A. English	Aug. 3	Sept. 19	10	27	1	17	8.9	83.8	40.4
Average	Aug. 2	Sept. 19	7	31	1	17	8.5	83.1	40.2
			Average Relative Results, %						
Upland	—	—	100	100	100	100	100	100	100
Bottom land	—	—	88	99	100	100	100	100	98

TABLE 3.—*Comparison of plant characters and yield of corn native to 10 upland Experiment Station during*

Source of seed	Year	Date tasseling	Date ripe	Suckers per 100 plants	Barren plants %	2-eared stalks %	Lodged stalks %	Shrinkage of ear corn %	Shelling %	Yield per acre, bu.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Upland	1923	Aug. 2	Sept. 28	22	31	3	19	11.4	85.6	68.4
	1924	Aug. 6	Sept. 22	3	32	0	15	1.9	82.9	29.4
	1925	Aug. 2	Sept. 23	7	17	0	23	6.1	83.0	37.0
	1926	Aug. 2	Sept. 10	5	69	1	15	13.6	80.3	6.4
	1927	Aug. 1	Sept. 13	5	4	1	14	9.5	84.1	62.6
Average	—	Aug. 2	Sept. 19	8	31	1	17	8.5	83.1	40.9
Bottom land	1923	Aug. 2	Sept. 28	19	30	4	22	10.7	84.8	68.5
	1924	Aug. 6	Sept. 22	3	31	0	13	2.9	82.8	27.8
	1925	Aug. 2	Sept. 23	4	18	0	20	7.5	82.7	36.5
	1926	Aug. 2	Sept. 10	4	69	1	16	11.6	81.3	5.8
	1927	Aug. 1	Sept. 13	4	5	1	13	10.0	84.0	62.6
Average	—	Aug. 2	Sept. 19	7	31	1	17	8.5	83.1	40.2
Average relative results, %										
Upland	—	—	—	100	100	100	100	100	100	100
Bottom land	—	—	—	88	99	100	100	100	100	98

10 bottom land farms in Lancaster County, Nebraska, grown at the Nebraska Experi-
5 years, 1923–27.

Individual plant measurements							Leaf area per lbs. grain, sq. in.†	Ratio grain to whole plant†	Ear measurements, inches		Kernel measurements, inches	
Height, in.		Leaf area, sq. in.	No. of leaves	Weight per plant, lbs.					Length	Diameter	Length	Width
Stalk	Ear			Stover*	Grain	Total						
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
						Upland						
84	38	1,056	15	0.34	0.31	0.65	3,662	0.474	6.3	1.9	0.47	0.32
84	39	1,073	15	0.33	0.30	0.63	3,899	0.467	6.3	1.9	0.47	0.33
83	39	1,081	15	0.35	0.29	0.64	4,058	0.450	6.1	1.8	0.47	0.32
82	36	1,010	14	0.36	0.29	0.65	3,889	0.450	5.9	1.9	0.47	0.33
87	40	1,117	15	0.36	0.31	0.67	3,807	0.463	6.7	1.8	0.46	0.32
86	35	1,194	15	0.40	0.29	0.69	4,019	0.446	6.4	1.9	0.47	0.33
86	39	1,143	15	0.39	0.37	0.76	3,268	0.493	6.9	1.9	0.46	0.34
84	37	1,077	15	0.34	0.32	0.66	3,697	0.479	6.1	1.9	0.46	0.33
88	40	1,079	15	0.37	0.25	0.52	3,943	0.479	6.0	1.8	0.47	0.31
88	39	1,064	15	0.34	0.30	0.64	3,734	0.468	6.1	1.9	0.47	0.33
85	38	1,089	15	0.36	0.30	0.66	3,798	0.467	6.3	1.9	0.47	0.33
						Bottom Land						
85	40	1,055	14	0.38	0.29	0.67	4,154	0.437	6.4	1.9	0.47	0.32
82	38	1,112	15	0.32	0.31	0.63	3,790	0.486	6.3	2.0	0.47	0.32
86	42	1,119	16	0.35	0.27	0.62	4,448	0.432	5.9	1.8	0.44	0.29
85	39	1,099	15	0.36	0.33	0.69	3,605	0.471	6.5	2.0	0.47	0.31
85	35	1,037	15	0.35	0.32	0.67	3,358	0.474	6.5	1.9	0.46	0.31
86	38	1,071	15	0.42	0.29	0.71	3,212	0.498	6.8	1.9	0.47	0.32
85	39	1,144	16	0.41	0.34	0.75	3,586	0.451	6.3	2.0	0.49	0.31
88	42	1,170	16	0.39	0.32	0.71	3,821	0.458	6.6	1.9	0.46	0.31
84	39	1,069	15	0.35	0.29	0.64	3,947	0.457	6.5	1.9	0.46	0.31
86	35	1,012	15	0.33	0.32	0.65	3,373	0.494	6.1	1.8	0.45	0.30
85	39	1,089	15	0.37	0.31	0.68	3,730	0.466	6.4	1.9	0.46	0.31
					Average Relative Results, %							
100	100	100	100	100	100	100	100	100	100	100	100	100
100	101	100	100	103	103	103	98	100	102	100	99	95

*Stover includes cob.
†The data in columns 18 and 19 are averages of ratios.

and 10 bottom land farms in Lancaster County, Nebraska, grown at the Nebraska
5 years, 1923–27.

Individual plant measurements							Leaf area per lb. grain, sq. in.†	Ratio grain to whole plant†	Ear measurements, inches		Kernel measurements, inches	
Height, in.		Leaf area, sq. in.	No. of leaves	Weight per plant, lbs.					Length	Diameter	Length	Width
Stalk	Ear			Stover*	Grain	Total						
(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
92	42	980	15	0.39	0.37	0.76	2,676	0.489	6.8	1.9	0.50	0.33
97	40	1,150	15	0.34	0.22	0.56	5,265	0.396	5.5	1.7	0.43	0.34
83	38	1,162	15	0.28	0.29	0.56	4,162	0.504	6.0	1.8	0.46	0.33
60	30	947	11	0.32	0.22	0.54	4,274	0.420	5.1	1.8	0.45	0.33
95	41	1,204	16	0.43	0.47	0.90	2,611	0.524	8.1	2.1	0.50	0.33
85	38	1,089	15	0.35	0.31	0.66	3,798	0.467	6.3	1.9	0.47	0.33
94	44	980	15	0.39	0.37	0.76	2,619	0.492	6.9	1.9	0.49	0.31
94	44	1,168	16	0.37	0.23	0.60	5,246	0.385	5.6	1.8	0.43	0.30
81	37	1,196	16	0.29	0.31	0.60	3,986	0.511	6.1	1.9	0.46	0.31
62	30	938	14	0.29	0.22	0.51	4,297	0.428	5.3	1.8	0.43	0.32
95	42	1,164	16	0.44	0.46	0.90	2,500	0.516	7.9	2.1	0.50	0.32
85	39	1,089	15	0.35	0.32	0.67	3,730	0.466	6.4	1.9	0.46	0.31
100	100	100	100	100	100	100	100	100	100	100	100	100
100	101	100	100	100	103	102	98	100	102	100	99	95

*Stover includes cob.
†The data in columns 19 and 20 are averages of ratios.

each condition in each locality. The results for each locality and the averages of all results are given in Table 1.

Comparisons between the two groups may be readily made by observing the ratios for the various plant characters of the upland to the bottom land corn. These ratios were as follows: (a) Suckers per 100 plants, 1.00; (b) barren plants, 1.00; (c) 2-eared plants, 1.00; (d) lodged plants, 1.00; (e) shrinkage of ear corn, 0.96; (f) shelling percentage, 1.00; (g) yield of grain per acre, 0.99; (h) stalk height, 1.00; (i) ear height, 1.00; (j) leaf-area, 1.01; (k) number of leaves per plant, 1.00; (l) stover weight, 1.00; (m) grain weight, 1.00; (n) total dry matter, 1.01; (o) leaf area per pound of grain, 1.00; (p) ratio of grain to whole plant weight, 1.00; (q) ear length, 1.02; (r) ear diameter, 1.00; (s) kernel length, 1.02; and (t) kernel width, 0.97. These ratios indicate no material differences between the upland and bottom land corn.

SEED SAMPLES FROM LANCASTER COUNTY TESTED INDIVIDUALLY, 1923–27

During the 5-year period of 1923–27, seed native to 10 upland and 10 bottom land farms which lie within a 10-mile radius of Lincoln, Nebr., was grown comparatively at the Nebraska Experiment Station. The results are summarized in Tables 2 and 3. Five-year averages for each of the 20 different lots of corn disclose some variation between the individual lots, but no material average differences between the progenies of the upland and bottom land seed samples.

Averaging the upland and bottom land varieties respectively for each of the 5 years, no material differences were evident between the two groups in any one year even though seasonal climatic variations were such as to cause a range in yield from approximately 68 bushels in 1923 to 6 bushels in 1926. The tables are referred to for specific comparisons.

MIXTURES OF SAMPLES FROM LANCASTER COUNTY, 1925–27

Native seed corn was obtained during each of the 3 years 1925–27 from 15 upland farms and 15 bottom land farms within a 10-mile radius of the experiment station. Composite samples of upland and bottom land seed, respectively, were prepared by mixing equal quantities from each farmer's corn. Plantings of these seed mixtures were replicated four times in alternating three-row plats which were 60 hills in length. Yields were based on the center rows. The results are summarized in Table 4. The performance of the two lots was nearly identical and no adaptive differences were noted.

TABLE 4.—*Comparative results from mixtures* of seed corn native, respectively, to upland and bottom land farms in Lancaster County, when grown on relatively fertile soil at the Nebraska Experiment Station during the 3 years, 1925–27.*

Source of seed	Year of test	Suckers per 100 plants	Barren plants %	2-eared plants %	Lodged plants %	Shrinkage %	Shelling %	Yield per acre, bu.
Upland	1925	7	15	1	22	9.0	82.8	40.9
	1926	6	64	1	21	5.8	79.7	7.3
	1927	6	4	0	14	12.0	84.0	72.3
Average		6	28	1	19	8.9	82.2	40.2
Bottom-land	1925	6	16	0	22	7.0	82.4	39.5
	1926	6	66	2	17	6.1	79.1	7.2
	1927	6	4	0	12	12.0	85.0	71.6
Average		6	29	1	17	8.4	82.2	39.4
Average relative results, %								
Upland	—	100	100	100	100	100	100	100
Bottom land	—	100	104	100	89	94	100	98

*Each seed mixture represents equal proportions of corn from 15 farms.

MIXED SAMPLES FROM LANCASTER COUNTY TESTED ON BOTH FERTILE AND INFERTILE SOIL, 1925

During 1925, mixed samples of upland and bottom land seed were prepared and planted in the same manner as in the test just previously described. In addition to being tested on fertile soil at the experiment station, the test was duplicated on relatively infertile soil 10 miles distant. The slight differences in results secured under the two conditions (Table 5) are not regarded as significant.

TABLE 5.—*Results from mixtures* of seed corn native, respectively, to upland and bottom land farms in Lancaster County, when grown comparatively on relatively fertile soil at the Nebraska Experiment Station and on relatively infertile soil 10 miles distant, 1925.*

Source of seed	Suckers per 100 plants	Barren plants %	2-eared plants %	Lodged plants %	Shrinkage %	Shelling %	Yield per acre, bu.
			Fertile Soil				
Upland........	7	15	1	22	9.0	82.8	40.9
Bottom land...	6	16	0	22	7.0	82.4	39.5
Difference.....	1	1	1	0	2.0	0.4	1.4
			Infertile Soil				
Upland........	4	15	0	19	7.4	83.0	30.9
Bottom land...	2	13	0	19	7.8	82.6	30.4
Difference.....	2	2	0	0	0.4	0.4	0.5

*Each seed mixture represents equal proportions of corn from 15 farms.

DISCUSSION AND CONCLUSION

Tests made during a 7-year period fail to disclose a difference in seed value of open-pollinated corn native to upland and bottom land soils within the same localities in eastern Nebraska. It is considered that the two types of conditions serving as seed sources differed chiefly with respect to soil fertility. In years of favorable rainfall the bottom lands under consideration have a potential yield capacity of approximately 75 bushels per acre compared with 40 bushels for the uplands. No material heritable differences were noted with respect to vegetative characteristics, or grain yield in relation to these conditions. This result is in agreement with that of Williams and Welton (5) who found no influence of soil fertility upon the seed value of corn.

In view of Hoffer's (1) determination of "heritable difference between capacities for nutrient and non-essential elements," it may be concluded that the soil differences herein considered were of in-

sufficient magnitude to result in a differentiation of strains of corn under the conditions of mass seed selection practiced on farms.

There is no extreme shortage of phosphorous in any of these Nebraska soils under consideration. Conditions of so pronounced phosphorous deficiency have been observed in some sections of the United States that an application of phosphate fertilizer very materially hastens the maturity of corn. It would seem that such striking physiological effects might readily result in the selection of plant types for seed on the phosphorous deficient soils that are inherently earlier maturing than would be the case where phosphorous is abundant.

Under representative upland and bottom land farm conditions within single climatic areas in eastern Nebraska and similarly situated with respect to soil moisture supply, there has been no evidence of associated heritable differentiation or adaptation of corn, and a free interchange of seed appears to be permissible. Although comparative data are not available, farm experience suggests that rather pronounced hereditary differences may prevail in cases where the bottom lands are subject to sub-irrigation or overflow, thereby resulting in a more favorable moisture supply.

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GROWTH OF BLUEGRASS WITH VARIOUS DEFOLIATIONS AND ABUNDANT NITROGEN SUPPLY[1]

L. F. GRABER and H. W. REAM[2]

In studies of plant growth during and subsequent to various defoliating treatments, cultures developed in the greenhouse offer means of control and facilities for quantitative determinations which are often not readily available under field conditions. Particularly is this true of grasses, such as bluegrass (*Poa pratensis*), where the subterranean growth consists of rhizomes and fibrous roots which are difficult to recover in the field and separate from extraneous material. It was the purpose of this experiment to ascertain some of the quantitative responses of top and underground growth of bluegrass during and subsequent to defoliations which were varied in height and frequency of removal. Such determinations were made on cultures of bluegrass with heavy nitrogenous fertilization and without fertilization. A review of the literature on food reserves is omitted intentionally for the purpose of brevity.

On May 11, 1929, 16 seeds of bluegrass were sown in each of 31 earthen-ware pots (8-inch) filled with a mixture of one-half fertile and sifted Miami silt loam soil and one-half quartz sand. With favorable conditions of light, moisture, and temperature in the greenhouse, the blades of the leaves attained a length of from 3 to 6 inches by July 15, 1929. At this time the grass was thinned to either one or two plants for each pot removing the less vigorous ones and allowing two to remain where a general lack of vigor prevailed. Aside from daily watering, no treatment was applied to any of the plants until October 5, 1929 (148 days after seeding), at which time the top growth from each culture was removed at a height of 1½ inches from the surface of the soil. This top growth was dried and weighed as indicated by the results tabulated in Table 1. The amounts varied widely and based on this variation the cultures were arranged in two groups each representing a progressive range of vigor in the plants from those yielding the least to those yielding the most. One of these groups in which the productivity of the plants ranged from 3.62 to 13.56 grams of top growth was fertilized with ammonium sulfate at weekly intervals beginning October 12, 1929, and ending January 11, 1930. During this time 4.2 grams of elemental nitrogen had been applied

[1]Contribution from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication April 16, 1931.

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Table 1.—*Effect of defoliations on the amount of top and subterranean growth of bluegrass (Poa pratensis) with and without abundant nitrogenous fertilization.*

Series No.	No. of cultures	No. of plants	Fertilization	First pre-cut, Oct. 5, 1929, ave. dry wt. of top growth in grams per culture	Pre-cuts from Oct. 12 to Dec. 27, 1929, inclusive			Subsequent growth from Dec. 27, 1929 to Apr. 29, 1930				
					Number	Height Inches	Ave. dry wt. of top growth in grams per culture	No. of after cuts*	Ave. dry wt. of top growth per culture in grams	Rhizomes		Fibrous roots
										Old	New	
1	3	5	Without nitrogen	11.5	10	½	4.6	8§	4.7	2.1	0.02	2.2
2	3	6		8.1	10	1½	6.3	8§	6.1	4.3	0.1	2.3
3	2	3		4.7	1†	1½	7.6	8§	8.5	4.8	0.1	3.1
4	3	3	With nitrogen	10.7	10	½	3.1	8§	2.0	2.1	0.002	3.2
5	2	2		8.1	10	1½	5.0	8§	10.2	2.3	0.4	4.2
6	2	2		4.5	1†	1½	10.3	8§	8.5	1.8	0.3	2.6
11	3	4	Without nitrogen	6.8	10	½	2.6	1‡	11.5	4.0	3.8	8.4
12	3	4		5.8	10	1½	2.5	1‡	14.4	10.1	2.6	7.1
13	2	4		4.2	1†	1½	5.3	1‡	17.6	12.3	2.2	8.5
14	3	6	With nitrogen	6.7	10	½	3.3	1‡	16.5	3.9	4.1	6.6
15	2	3		5.8	10	1½	2.8	1‡	50.7	7.3	4.0	10.4
16	3	5		3.9	1†	1½	7.1	1‡	42.2	6.4	2.9	11.2

*Taken ½ inch above soil surface, except last removal on April 29 which was clipped near rhizomes.
†Removal was made on Dec. 27, 1929, after 148 days of growth.
‡Removal was made on Apr. 29, 1929, after 83 days of growth.
§These removals were made on Jan. 3, 11, and 18; Feb. 26; Mar. 4 and 29; and Apr. 18 and 29, 1930.

to each culture. The other series was not fertilized and the amount of top growth removed from these cultures on October 5 varied from 4.08 to 15.46 grams.

The cutting treatments which were applied subsequent to October 5 are indicated in Table 1. Since the plants had 148 days of uninterrupted growth before cutting was begun, they were well established and the level of organic reserves may be regarded as being high. The defoliations from October 12 to December 27 were designed to lower materially the reserves by 10 clippings at a height of ½ inch above the soil surface in series 1, 4, 11, and 14 of the unfertilized and fertilized cultures. In series 2, 5, 12, and 15 a much less drastic lowering of the reserves was made by clipping with the same frequency but at a height of 1½ inches. In series 3, 6, 13, and 16 the reserves were maintained by cutting only once on December 27, 1929. These defoliations, including the initial one on October 5, are called pre-cuts. The subsequent cuttings (after December 27) were planned, in part, to measure the after-effects of the three "pre-cutting" treatments. These measurements were made by eight clippings between January 3 and April 29, 1930, in cultures of series 1 to 6, and by one clipping of the remaining cultures (series 11 to 16) on April 29. Also, on this last date the amount of root and rhizome growth was determined. With the exception of the last clipping on April 29, which was taken very close to the soil surface, all other after-cuts were removed at a height of ½ inch above the soil surface.

TOP GROWTH

An interpretation of the data in Table 1 cannot be made without reference to variations in the original vigor of individual plants and the preferential selection of cultures for the various cutting treatments. By intention the plants with the least vigor (series 3, 13, 6, and 16) were given the least drastic defoliating treatments. Reference to the productivity of the plants with the initial clipping taken October 5 clearly indicates that the more productive plants (series 1, 11, 4, 14) were used for the most frequent and closest pre-cuts. Series 2, 12, 5, and 15 were intermediate in their initial vigor of growth and in treatment.

The amount of top growth produced by the various cultures subsequent to the last pre-cut on December 27 has varied widely in accordance with fertilization and cutting treatments. Such results are portrayed graphically in Fig. 1 from data given in Table 1. Wherever the reserves were reduced by pre-cuts and by eight subsequent cuttings, there was no significant increase in the top growth from very

heavy nitrogenous fertilization. In other words, organic foods were the limiting factors in subsequent growth which precluded a noteworthy response from fertilization. Without sufficient carbohydrates the plants did not utilize an abundant supply of available nitrogen. However, when a productive level of carbohydrate reserves was maintained by the height or infrequency of removal of the pre-cuts

TOP GROWTH OF BLUE GRASS
(DRY WEIGHT IN GRAMS)

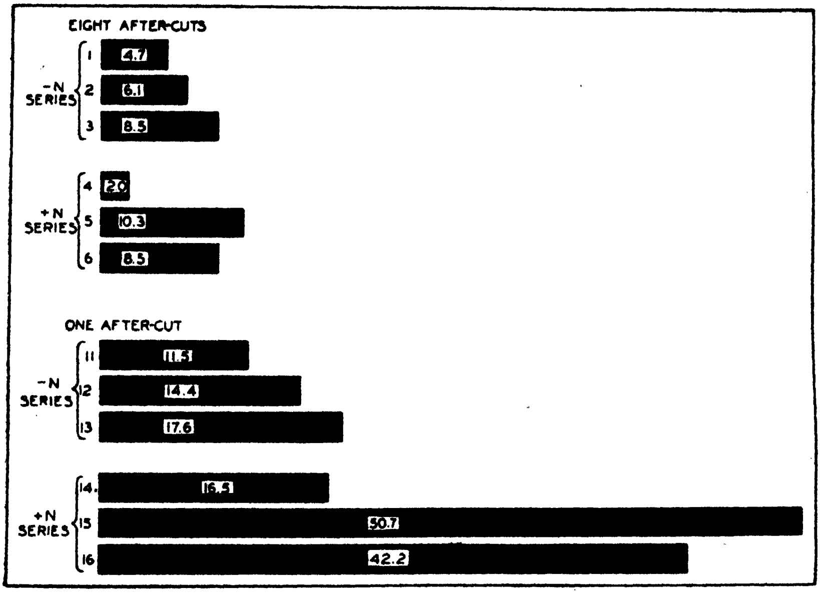

FIG. 1.—Heavy nitrogenous fertilization (+N) only stimulated abundant vegetative growth when the defoliations permitted accumulations of carbohydrate reserves. Thus, when frequent and close pre-cuts were followed by eight close after-cuts, the surplus of organic foods was at a very low level and a negative response (series 1 and 4) occurred with fertilization. However, where the precuts were less drastic (as in series 2, 3, 5, and 6), the food reserves were sufficient to give a moderate and positive response from fertilization. With only one after-cut, the plants accumulated carbohydrates and top growth was greatly increased by fertilization. This increase was much less, however, with series 11 and 14 which received the most drastic pre-cuts.

and where such a level of reserves was continued and augmented (series 11–16) by only one after-cut, a very marked increase in top growth of from 44 to 252% resulted from abundant nitrogenous fertilization.

It is very apparent by comparing series 1 with 2, 4 with 5, 11 with 12, and 14 with 15 that the height as well as frequency of the pre-cuts has had a profound effect on subsequent productivity giving further

evidence that the photosynthetic parts of plants which remain after cutting are potential sources of reserve foods. The extent of such remnants is of vital significance in the maintenance of reserves under various systems of defoliation.

SUBTERRANEAN GROWTH

The amount of subterranean growth did not vary nearly as widely as that of the top growth. The increases and decreases (Fig. 2) from fertilization were relatively small. However, there was a marked increase in the underground growth of all cultures where one after-

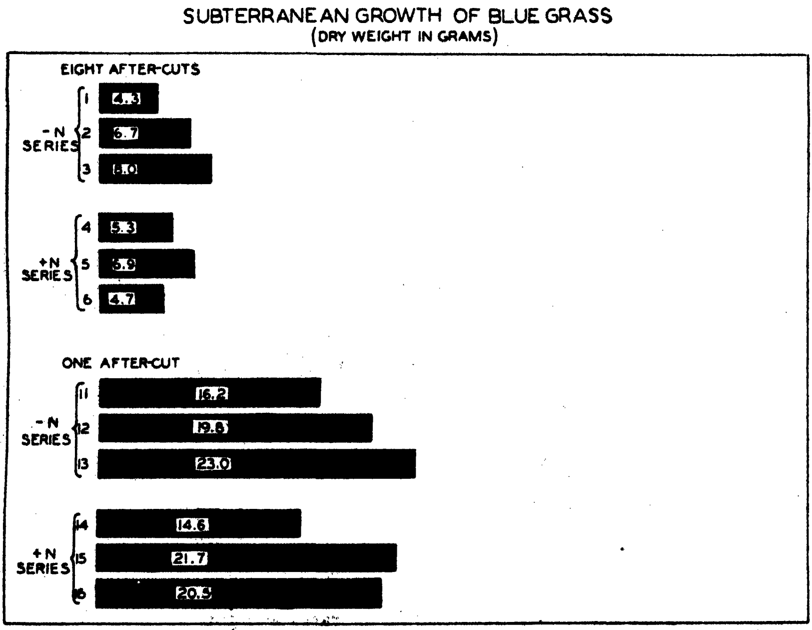

FIG. 2.—In this experiment very abundant nitrogenous (+N) fertilization of bluegrass did not influence root and rhizome growth materially, but frequency and height of defoliations had a prominent effect on underground development. With the accumulation of organic foods resulting from only one after-cut at the close of a period of 123 days of growth subsequent to the pre-cuts, a pronounced increase occurred in both fertilized and unfertilized cultures when compared with those given eight defoliations during the same period of growth.

cut (series 11 to 16) was removed instead of eight. The reductions in photosynthetic activity by frequent defoliations prevent the accumulation of organic foods essential for rhizome and root growth. With eight after-cuts (series 1 to 6) the amount of new rhizome growth was very limited, especially in comparison with that of the

cultures given one after-cut. As was true with top growth more abundant subterranean development occurred with the higher level at which the pre-cuts were taken. Since less vigorous plants were chosen for the taller defoliations these results are significant.

DISCUSSION

This experiment was conducted with cultures of one or two individual plants of bluegrass established from seed sown in 8-inch pots of fertile soil. These cultures represent a much different situation than would prevail in a heavy seeding of bluegrass in fields or plats where dense populations of plants prevail. Under such conditions, Graber[3] has shown that heavy nitrogenous fertilization compared with no fertilization has reduced the subterranean growth of grass given various defoliating treatments, including those which permitted heavy accumulations of top growth. Graber explains that in addition to other factors, the exclusion of sunlight from new leaves by old growth may be an important factor in the curtailment of subterranean growth. The new growth being partially etiolated for a considerable period due to density of the old growth is largely established in its early stages from previously stored foods, and at the expense of root and rhizome growth. He also states that such etiolated growth is often killed by sudden exposure to sunlight after cutting which delays the recovery of the grass and at least temporarily retards its regenerative activity. With the individual plants used in this experiment, there was less opportunity for this condition to prevail.

Since the period during which the clippings of top growth were made was largely during the winter months when the days were short and often cloudy, photosynthesis was limited accordingly and the effects with reference to reserves were probably amplified especially with frequent and close removals of top growth.

During the fore-part of January nitrogen applications seemed to have a retarding effect on growth where the carbohydrate reserves were greatly reduced by frequent clippings. This may have been, in part, a toxic effect due to abundant applications, and for this reason fertilization was discontinued after January 11, 1930. While the nitrogen applications were abundant, their utilization in stimulating top growth (to a much less extent rhizome and root growth) was,

[3]GRABER, L. F. Insect injury of bluegrass in relation to the environment. Ecology, 12:547–566. 1931.

————. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiology, 6:43–72. 1931.

nevertheless, effective where the plants were allowed to accumulate sufficient carbohydrates. It should be emphasized, however, that with the very heavy applications of nitrogen in this experiment the results are not interpreted as being specifically or directly applicable to fertilizations common in field practice.

Minor differences in the amounts of top and subterranean growth are not discussed in lieu of the variability of the cultures at the beginning of the defoliations.

SUMMARY

The effect of partial defoliations and heavy nitrogenous fertilization was studied through the medium of pot cultures each containing one or two plants of bluegrass. Those defoliating treatments which reduced the organic reserves, curtailed the immediate and also the subsequent productivity of the plants on both fertilized and unfertilized cultures of bluegrass. Only when a productive level of reserves was maintained by height or infrequency of cuttings did the plants utilize an abundance of nitrogen to stimulate abundant vegetative growth.

With the accumulation of organic foods resulting fron only one defoliation at the close of 123 days of growth, subsequent to the precuts, a pronounced increase in root and rhizome growth occurred in both fertilized and unfertilized cultures of bluegrass compared with those given eight defoliations during the same period.

NOTE

AMMONIUM THIOCYANATE AS A WEED ERADICANT

Ammonium thiocyanate has been known for many years to be a plant poison, yet it has not been applied for weed eradication. Suggestion of the use of this compound was made by Dr. Paul Peterson of the Kopper's Research Laboratory, and samples of ammonium thiocyanate, crude thiocyanate liquor, and a liquor containing tarry residues (called "Weed Killer") were supplied by the Kopper's Company for our experiments.

The ammonium thiocyanate in crude crystalline form was applied both dry and in water dilution. Ammonium thiocyanate is very soluble in water and can be made up in as high concentration as 8 pounds per gallon of water. A more dilute solution, 2 pounds per gallon, is more desirable for use with a sprayer. The thiocyanate liquor and "Weed Killer" were applied in dilutions of 1–100, 1–10, and 1–5, using 1 gallon per square rod. The thiocyanate liquor contained approximately 20% ammonium thiocyanate.

Screenings from seed-cleaning operations were obtained from Northrup, King & Co. The seeds of practically all of the common weeds of Minnesota made up a greater portion of this seed. This seed was sown on good soil at University Farm—1 bushel on 24 square rods—and the seeds harrowed into the soil. This gave a very thick stand of a great variety of weeds. Square rod areas were laid off at the time of planting the weed seeds, and these were treated with the weed-killing solutions after the seeds had sprouted. Two weeks and four weeks after applying the thiocyanate, corn, wheat, and peas were drilled across the plats. The plats were not cultivated.

On a square rod which received 10 pounds of ammonium thiocyanate there were no weeds or crop plants growing after 12 weeks. On a plat which received 5 pounds per square rod a few green foxtail (*Setaria viridis*) plants were growing, but no crop plants. The plats which received 2 pounds per square rod showed a number of foxtail plants and some lamb's quarters (*Chenopodium* sp.) Corn made good growth on this plat and had a dark green color, but certain areas showed killing of the seed when planted 2 weeks after the thiocyanate application. When the corn was established, it grew well. One pound per square rod killed a considerable percentage of the weeds and none of the crop plants, but owing to the greater number of weeds on this plat, the crop plants were not as green or large as on the plat which received 2 pounds per square rod.

Corn, peas, and wheat were planted on the plats 4 months after treating and gave good stands on the plats which received 1, 2, and 5 pounds per square rod. The plat treated with 10 pounds showed practically no germination. The crude thiocyanate liquor evidently contains more tar than solutions of the crude crystalline thiocyanate. This does not seem to give much more permanent injury than the thiocyanate. The "Weed Killer," containing tar residues, had a much more lasting effect than the thiocyanate or thiocyanate liquor.

If heavy doses of thiocyanate are put on, 10 pounds per square rod, there is sterilization of the area for at least 4 months. If only 2 pounds are put on, the weeds are mostly killed, yet the soil is not sterile for more than 2 to 4 weeks, and the dark green color of the foliage indicates even a beneficial effect, perhaps from the nitrogen supplied by the thiocyanate. With 5 pounds per square rod the toxic effect disappears in less than 4 months.

Thiocyanates, when sprayed onto weed leaves, produce death and discoloration within 2 days. The discoloration of leaves of Canada thistle and sow thistle can be seen within 2 hours after applying. Ammonium thiocyanate is appreciably soluble in oils and sticks well to the waxy surfaces of leaves. The salt absorbs moisture from the air and deliquesces. Rain dissolves the salt and carries it from the leaves to the ground, from which it is quickly absorbed by the roots. A test for thiocyanate in stalks with ferric chloride solution shows quick passage up the vascular system.

Organisms in the soil have been shown to decompose thiocyanates with the liberation of H_2S from the acid radicle. Thiocyanates also react with iron to produce a colloidal compound. Both of these

agencies evidently lead to a decomposition and removal of the toxic salt from the soil and leave the ammonia, which acts as a fertilizer, as well as sulfur compounds, which are desirable as fertilizer elements. The reaction with iron allows the neutralization of the excess of thiocyanate by a second application of a solution of a ferric salt. The colloidal red ferric thiocyanate, produced by the reaction of ferric chloride with ammonium thiocyanate, is not toxic to plants. This offers a means for removal of the toxic action before it is desired to plant a crop.

Spraying a solution made from 1 to 5 pounds of ammonium thiocyanate to 1 gallon of water onto the leaves of thistles, burdock, quack grass, poison ivy, prickly ash, scrub oak, nettles, etc., killed the leaves quickly, and if the leaves were well covered, the salt was washed off into the soil and killed the whole plant.

Dry ammonium thiocyanate can be sprinkled around the base of the shrub or plant, adjusting the size of dose to the size of the plant. A seeding burdock 4 feet tall requires a tablespoonful of dry thiocyanate applied around the base to kill it. The dose applied, must be varied to suit the extent of the root system and to the plant's ability to throw up new shoots. Scrub oaks an inch in diameter require 1 to 2 tablespoonfuls of dry thiocyanate to kill them.

Thiocyanate liquor is made by every coke plant. The crude liquor contains sodium thiocyanate up to 5%, sodium thiosulfate about 5%, and other sodium compounds. These have an alkaline reaction and produce a longer toxic effect than ammonium thiocyanate. The crude sodium thiocyanate liquor is not suited for field application. It can have fertilizer value only from the sulfur and possibly some nitrogen from the decomposition of the CNS radicle by bacteria. For field applications it is better to use ammonium thiocyanate solutions, which probably yield fertilizer value from all of the nitrogen and sulfur which they contain. The crude liquor from gas plants is a good eradicant for bunkers of golf courses, driveways, etc., and in this use is more desirable than combinations of sodium chlorate and calcium chloride. The latter are not as effective pound for pound, and also they stick to the shoes of players and are carried onto the greens, where they cause discoloration of the grass. Small doses of ammonium thiocyanate, 2 to 4 pounds per gallon, can be used with advantage in killing dandelions in lawns.—R. B. HARVEY, *Minnesota Agr. Exp. Station, St. Paul, Minn.*

BOOK REVIEWS

KEIMUNGSPHYSIOLOGIE DER GRÄSER (GRAMINEEN) (PHYSIOLOGY OF GERMINATION OF GRASSES)

By Ernst Lehmann and Fritz Aichele. Stuttgart: Ferdinand Enke. XXIII + 701, illus. 1931. Unbound R. M. 60; bound R. M. 63.

In work with field crops, problems concerning germination are frequently of great importance. The literature dealing with seed germination is very extensive and deals with so many varied phases

of the problem that it is impossible for even the specialist to know all the literature bearing on his work. Agronomists and other workers in applied fields are liable to miss contributions that would be valuable to them in their work. Lehmann and Aichele have recognized the need of a key to the vast literature of seed physiology and have attempted in this work to classify and make available the literature dealing with the physiology of germination concerning one group of plants—the grasses.

The field covered in this book is indicated in the sub-title—"A life story of ripening, resting, and germinating grass seeds." The table of contents is itself of value as a comprehensive detailed classification and analysis of our knowledge of the grass, fruit, and seed during development, during rest, and during germination. Morphology, chemical composition, changes in form and in composition, response to environment, including response to chemical treatment for diseases, are considered both for the general group and for each species. Other topics are: Duration of viability under various conditions; respiration of resting grains; after-ripening; methods of testing germination; influence of water, chemicals, temperature, and light on germination; transformation of materials during germination; and respiration during germination. Not only theoretical, but also practical aspects are included.

Apparently no attempt has been made to summarize present knowledge on germination, but the book furnishes a guide to the literature, leaving the reader to obtain his information from the originals and to draw his own conclusions as to the value of results given. In the text a brief summary is given for each topic followed by annotated citations of the literature. Many illustrations, graphs, and tables are copied from the cited literature. In seeking definite information on a specific problem one is disappointed with the meagre summaries of the facts about any given subject. It is unfortunate that many papers that would aid in understanding the problems under discussion are not mentioned because they are not based on work with the grasses.

As a searching analysis of the problems and a comprehensive guide to the literature the book should serve a very useful purpose in a field that has not been covered in recent years. There is, however, still great need for a summary and digest of the known facts of seed germination. (E. H. T.)

MAIZE IN SOUTH AFRICA

By A. R. Saunders. Johannesburg: Central News Agency, Ltd. 284 pages, illus. 1930. 20s.

This is what would be expected from the title. In the States, a larger part will interest those who know less and a smaller part those who know more about maize. At that, Chapters II and III, discussing the production in South Africa and the relation of production to climate; Chapter VIII on varieties; and Chapters IX and X on diseases and insect pests of maize contain much information that should interest American agronomists working with corn.

The other chapters, on soils and fertilizers for maize, and on its botany, culture, breeding, uses, etc., are the usual thing. They should be of value to those for whom the book presumably was written, the South African maize growers. (F. D. R.)

AGRONOMIC AFFAIRS

NEWS ITEMS

T. H. GOODDING, Associate Professor of Agronomy at the University of Nebraska, is on leave of absence for work on a doctorate degree at Cornell University. Mr. Goodding plans to return to Nebraska, September 1, 1932.

RALPH WEIHING, 1930 graduate of the State Agricultural College of Colorado; Ira Clark, 1931 graduate of Utah State Agricultural College; Boyd Faulkner, 1931 graduate of the University of Idaho; and Lawrence Newell, 1927 graduate of Hastings College, in Nebraska, are working on a fellowship basis toward masters degrees in the Department of Agronomy, University of Nebraska.

J. O. CULBERTSON, who received his master's degree at the University of Nebraska in 1930, has accepted a position with the Office of Sugar Plants, U. S. Dept. of Agriculture, as Assistant Agronomist. He is stationed at Salt Lake City.

O. E. OVERSETH, formerly an instructor in soils at Iowa State College and more recently in charge of the western office of the Synthetic Nitrogen Products Corporation with headquarters at Toledo and Indianapolis, has returned to Iowa State College to complete his studies for the doctorate degree in soils.

HOWARD MILLER, who has been Smith-Hughes instructor and principal of the Hinckley High School at Hinckley, Illinois, for the past few years, has returned to Iowa State College to pursue graduate work in soils.

L. G. THOMPSON received the doctorate degree in soil bacteriology at Iowa State College in June. At the beginning of the school year he joined the staff of the State Teachers College at Johnson City, Tennessee.

ON SEPTEMBER 30, the Iowa Section of the American Society of Agronomy held its annual fall mixer in honor of the new members and graduate students in farm crops and soils. Forty-four persons were present. The first regular meeting of the year was held October 14 when Professor W. I. Griffith of the Engineering Extension Division at Iowa State College spoke on "The Radio as a Factor in Agricultural Education."

HOWARD L. HYLAND, Assistant in Forage Crops at the Iowa Agricultural Experiment Station, has resigned to accept the position of Senior Scientific Aide in the Office of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. After completing some cooperative experimental work at Ames, Mr. Hyland will be located at Washington, D. C.

LORENZO D. EAGLES, who has been doing graduate work in farm crops at Iowa State College, was appointed Assistant in Forage Crops at the Iowa Agricultural Experiment Station, effective October 1.

CLYDE McKEE, Agronomist and Vice-Dean of Agriculture at Montana State College, has officially resumed his duties after spending the year July 1, 1930, to July 1, 1931, in sabbatical leave. He spent the first three months of his leave visiting experiment stations in the Great Plains and Atlantic seaboard and studying in the library of the U. S. Dept. of Agriculture at Washington. The remainder of his time was used in doing graduate work at the Kansas State Agricultural College where he received the degree of Master of Science in Agronomy.

JOURNAL
OF THE
American Society of Agronomy

VOL. 23 DECEMBER, 1931 NO. 12

CONTRIBUTIONS OF AGRONOMY TO THE DEVELOPMENT OF THE GREAT PLAINS[1]

W. W. BURR[2]

There are two reasons for choosing this particular topic for my address this evening. First, several of my eastern friends have suggested it, and, second, my first-hand experience in dry farming has been entirely in the Great Plains region. That region differs from other dry-farming sections largely in the distribution of its rainfall, and the agronomic practices and problems vary accordingly. To the men long in this work, my address may seem only a restatement of things already known and many times discussed. To the men who have only recently come into the field and to our colleagues from the East I trust it may occasion new lines of thought and interest.

In the topic the word "development" is used instead of "reclamation" because the latter term implies a degree of accomplishment and finality not warranted by the brief span of years now recorded. This is particularly true of certain sections.

In order to give a proper setting to my remarks, it may be well to describe the area and to review briefly some of the early history of the Great Plains. Probably the settlement of no other section of our country is so rich in the romance of hope or so tragic in its failures and disappointments as that particular section.

The area comprises some 400,000 square miles, extending from the hundredth meridian westward to approximately the 5,000-foot contour line on the eastern slope of the Rocky Mountains, and from the Park belt of Canada south to Mexico.

The topography is level to rather abruptly rolling prairie; the surface soil generally fertile and free from stone. The subsoil varies

[1]Presidential address delivered before the twenty-fourth annual meeting of the Society held in Chicago, Ill., Nov. 19, 1931.

[2]Dean, College of Agriculture, University of Nebraska, Lincoln, Neb.

from loess mantles 100 or more feet in thickness to a residual debris underlain by rock or rock-like material but a few feet below the surface. The cover is mostly short grass consistent with the limited rainfall, with no timber or brush except along streams or in swales where additional water is obtained by runoff. While there is a remarkable uniformity throughout this large area, there is, nevertheless, a wide variation in soil types and climatic conditions. This immense area has all the requisites of a rich agricultural empire, except that of a regular and dependable supply of rainfall.

The rainfall of the area varies widely, largely within the recognized limits of dry-farming, which are the rainfall lines of 10 to 20 inches. Some truly dry-farming sections in the central and southern Great Plains receive even more than that. There are wide annual fluctuations in both the amount and distribution of the rainfall of a given locality. This fluctuation in distribution, even to a greater extent than the total amount of rainfall, makes crop production hazardous throughout the Plains. In amount, it may be said that the rainfall of a locality varies from almost arid to almost humid conditions throughout a period of years. For example, the rainfall at North Platte has varied during the last 20 years from an annual of 10 inches to an annual of more than 40 inches. Obviously, with the latter rainfall, any method of tillage produces bountifully. In some years the rainfall may be so distributed that even a small total, coming at just the right time, produces satisfactory crops. Again, a larger amount will be so unfavorably distributed that more or less failure results. However, rainfall alone does not determine the success of dry farming. Other factors, especially the rate of evaporation, together with the rate of transpiration of water through the plants, are important. In the southern portion of the Great Plains the rate of evaporation during the growing season is approximately double that of the northern Great Plains. A 15-inch annual rainfall in North Dakota may have the same crop-producing ability as 25 inches of rainfall in the southern Great Plains.

The fact that the land is generally level and the soil rich and free from stone has made the Great Plains area very attractive to settlers. Prior to 1860 the only settlers in the country were cattlemen, whose herds grazed over large areas. These early cattlemen generally made no provision for winter feeding, and the losses in storms and through starvation in winter were large.

Between 1860 and 1900 several attempts were made in a number of sections of the plains to develop the land for farming purposes. The rapid increase in population and the settlement of the country

to the east forced the new settlers into this region. These people brought from their homes in the east the machinery, tillage methods, and the seeds of crops they had formerly used, all of which were adapted to conditions farther east. During the so-called good years they got on fairly well, but with the coming of dry years they failed and starved out. Thus the settlement receded again toward more favorable conditions. In some sections of western Kansas and Nebraska there were at least three attempted settlements and three more or less general failures before 1900.

The question is sometimes raised as to why the failures of settlers were so much more numerous in the Great Plains than in the Great Basin or Inter-Mountain country. The reason probably is that the settlers who went into the Great Basin and Inter-Mountain regions fully realized when they crossed the mountains that they were going into new environment. The settlers in the Great Plains had crossed no natural barriers. They merely moved westward with the pressure of population and they moved largely in cycles of good years. They no doubt noted that the vegetation of the prairie became shorter and less dense, that the blue stems gave way to short grasses, but they did not fully realize what this meant, and attempted to use the same methods and to grow the same crops that they were accustomed to in Iowa and Illinois. In fact, there was no information then available that this was not the proper thing to do, nor were the better-adapted crops then available, even had the need been recognized.

The question of settlement of the Great Plains, involving as it did parts of nine states, became of vast economic importance. The tragedy of those who attempted to settle and who later were driven away by starvation kept the question continually before the people. The problem became so acute that it was finally considered by Congress. In the late eighties the Senate appointed a committee to study the whole question of farming in the so-called arid districts. In the minority report of this committee in 1890 we find the following:

"In some years the rainfall is ample; in other years it is entirely insufficient, and in such seasons the farmer reaps no reward for his toil. The history of farming for the past two decades in this subhumid region is full of instructive lessons. Experience shows that wet and dry years alternate in groups. Two or more wet seasons will be followed by two or more dry seasons. When a period of sufficient rainfall comes for several years in succession, settlers enter upon the subhumid lands in greater numbers, tempted by the fertility of the soil and the salubrity of the climate, and their first years are marked by prosperity, especially in those regions where great

wheat fields can be cultivated at small expense; but when a succession of dry years appear, and one crop after another fails, the wealth of the people melts away. For the means of subsistence the people mortgage their lands. Horses, cattle, and sheep must be dispensed with, because they devour the subsistence which wives and children need, until at last hunger drives the people away. In the meantime the money-lenders and speculators foreclose their mortgages and get possession of the lands, and when seasons of rainfall come, another period of land speculation is developed, and the lands are cultivated as farms by people who in their turn must be ruined and driven from the country. Such years of disaster have come two or three times to some portions of the subhumid region. Kansas has been the scene of suffering three times, and in North Dakota and South Dakota the people are now passing thru such a period. The disaster that arises from these years of poverty is greatly aggravated by the land speculators, who, with wealth at their command, are enabled during years of plenty to create a belief among the people that the climate is permanently changed, and, fixed in this opinion, the settlers fail to provide against the years of want.

"Perhaps in the history of the United States, there has never been so large a body of people so hopelessly ruined by false representation and speculative chicanery as the people who have settled from time to time in this subhumid region."

The following quotation is from an article by M. A. Simmons in the American Farmer of about that same time:

"From the 98th meridian west to the Rocky Mountains there is a stretch of country whose history is filled with more tragedy, and whose future is pregnant with greater promise than perhaps any other expanse of territory within the confines of the Western Hemisphere. For many years it was marked upon the maps as a great white blank indicating an inhospitable desert. Finally as the territory bordering upon it became more thickly settled and the pressure for land became ever fiercer, the line of social advance rose and fell with rain and drouth like a mighty tide beating against the tremendous wall of the Rockies and every wave left behind it a mass of human wreckage in the shape of broken fortunes, deserted farms and ruined homes."

This ebb and flow of settlement almost destroyed the faith of many sound citizens in the value of the Great Plains as a farming section. As late as 1908, Henry Wallace, Sr., told me that the government had seriously erred in allowing any attempt at farming in Nebraska west of North Platte; that the limitations of climate were so severe as to preclude the possibility of success. With the meager information then available concerning the possibilities of combating drought this was probably true. Theories which always find their most congenial habitat in the absence of established facts were still numerous and prevalent. So-called systems of dry farming,

often conceived from some single instance of success, were heralded as salvation to the agriculture of the section. Many of these theories were plausible, and the individuals who promulgated them were honest. The trouble was that the enthusiastic support of any of them as a panacea for all the ailments of dry-land agriculture kept open a most fertile field for the unscrupulous exploitation of land values. The theory that the climate was changing, that rainfall follows the plow, or the advocacy of some system, recently discovered, that would make possible the growing of crops under conditions where without it such production was impossible, was to say the least a strong argument for the sale of land at prices beyond its value at that time.

In the early part of the present century helpful information on dry farming was already available in some western states, especially California and Utah, but was not generally known to the settlers in the Great Plains. At that time steps were taken by several of the states and by the federal government to get definite information regarding both the limitations and possibilities of agricultural development in that area. Up to that time most of the Great Plains farmers had not remained long enough to make their experiences a safe guide to practice. A few, however, had remained and their experiences had begun to crystallize into definite information. There was one fact upon which all agreed, and that was that the rainfall was insufficient for farming under the methods which the settlers had used when living farther east. It is natural, therefore, that one of the first lines of investigation started should deal with the accumulation of water in the soil.

During the period from 1902 to 1905 several states established experiment stations to study the problems of dry farming. From 1905 to 1909 the U. S. Government entered into cooperation at 11 stations in seven of the Great Plains states. Subsequently, a number of other stations were established either by the states alone or in cooperation with the U. S. Dept. of Agriculture. At the beginning the work at most of the stations was largely agronomic. Later more of the stations enlarged their programs to include animal investigations. Never before nor since has a nation undertaken such a comprehensive plan of regional agronomic investigations, and the plan has been followed through. At several of the stations, the original rotations are now in their twenty-sixth year. At a number of stations there are now 25 years of soil moisture records. Meteorological records have been kept at each station to show rainfall, wind velocity, humidity, and rate of evaporation. The actual data

records of the factors affecting crop production in the Plains are now voluminous indeed.

It is impossible in a brief paper such as this to give much detail concerning the studies that have been made or to attempt to give credit to the individuals who carried them out. It seems better to enumerate some of the findings that have been important in determining the agronomic practices that now obtain.

An outstanding agronomic contribution to the agriculture of the Great Plains has been in the field of soil moisture. In studying moisture conservation it was soon found that so far as field practices are concerned, there are only two factors to be considered, first, getting the water into the soil, and, second, preventing its escape. The former deals largely with surface tillage and the latter with preventing weed growth. The application of these simple principles, as with others, must vary with environmental conditions, in this case the principal one being soil type. To get water into a sandy soil requires little attention to the surface; a clay surface needs more cultivation. All gradations between these two types are found in the Great Plains.

The major soils of the area were found to have a high water-holding capacity. The fine sandy loams and silt loams, which cover most of the Plains, hold from 1½ to 2 inches of available water per foot. It is not possible to accumulate that amount of water every year, the important factor in that respect being the amount and distribution of the rainfall for the period. It was found that isolated showers even to a half inch of water are held near the surface and lost through the rapid evaporation which occurs there. Heavy downpours puddle the surface and increase the loss through runoff. The loss from that source has been known to be above 80% of the total rain. These findings were of considerable practical significance to the whole question of tillage to conserve moisture.

At the beginning of the investigations deep tillage to increase the soil reservoir and establish a deep feeding zone for the crops was being advocated quite widely. Special machines were built for this purpose. Except perhaps in cases of extremely heavy soil, deep tillage was not found beneficial. The soils of the Great Plains region are generally deep. They do not have a distinct subsoil or plow sole, impervious to water or plant roots. If water is available in contiguous lower soil strata and if it is needed, the crops will normally feed to considerable depths. Corn and spring-sown small grains will send their roots into the soil 4 or 5 feet, or even more, and winter wheat 6 feet or more, to obtain water. Stirring the soil an

additional 8 or 10 inches, therefore, had little effect and increased the tillage cost. In some cases yields were actually decreased, which may have been due to the loss of water because of increased vapor movement.

When these investigations first started it was thought that capillarity brought the moisture from the subsoil to the plant roots and also to the surface where it was lost unless the capillary movement was interrupted. A dust mulch was advocated to prevent moisture loss, but was soon found to have several serious weaknesses. Pulverizing the soil to obtain a dust mulch is extremely dangerous because of soil blowing. Extensive damage has sometimes resulted from it. The second difficulty was that the dust mulch would not readily admit water. Rain falling on the fine mulch quickly puddled the surface and to a large extent was lost because it could not get into the soil. The ideal surface is one that is given enough cultivation to keep down weeds, but is left rough enough to reduce runoff to a minimum. Naturally, a large amount of labor was required to maintain a fine mulch, and its abandonment has meant a much lower labor cost to the farmers.

As previously stated, when these investigations started, the loss of water from the soil was largely attributed to its being brought to the surface by capillarity. Agronomists soon found that under dry-land conditions capillarity operates too slowly in bringing water from the subsoil to be of material benefit to the growing crop or a serious source of water loss. In all of our own data there is no evidence of any appreciable movement of water toward the surface by capillarity, except in subirrigated areas where sheet or free water is present. As evidence of capillarity it was pointed out that a slow but gradual movement toward equilibrium was taking place between moist and dry layers of soil in the deeper sub-strata, quite removed from the vaporizing environment at the surface. Later data, yet unpublished, by Russel, Weakley and myself, show this movement to be in the vapor phase since it takes place across gaps in the soil almost as freely as when the soil layers are contiguous.

Experimental data prove that under dry-land conditions, water once in the soil deeply enough to escape the rapid drying at the surface largely remains there until it is reached and removed by plant roots. There is always some loss of water from the soil by evaporation, the water escaping as vapor, rapidly at the surface and more slowly from the deeper strata, through openings enlarged by the shrinkage of the drying soil above. Cultivation reduces this minor loss by checking vapor movement.

The investigations of the water requirements of plants by Briggs and Shantz, by Kiesselbach, and by others pointed out the greater efficiency in the use of water by well-adapted crop varieties and bore out the field evidence of the importance of weed eradication. Probably most of the Great Plains agronomists today and the farmers themselves feel that the maximum in moisture conservation is attained when weeds are entirely absent, no matter how this is accomplished. Their only other concern is a surface that will not blow. Insofar as weeds are allowed to develop, either in the preparation of the seedbed, or in the growing crop, to that extent under normal conditions they will reduce crop yields.

From the standpoint of accumulating water in the soil summer tillage has been found the most efficient practice yet devised. The practice is to leave the land uncropped for a year, keeping the surface free from weeds and receptive of water. At the outset there was considerable information available concerning this practice. In Utah, California, and the inter-mountain states it was already in successful use. During seasons when the rainfall is favorable in both amount and distribution, the soil can be filled to carrying capacity to the full depth of the crop-feeding zone. In seasons of less favorable rainfall the water accumulation is reduced accordingly. From extended investigations at the several stations during the past 20 years, it has been found that from 11 to 40% of the rainfall of any certain season can be held by summer tillage. The amount retained will vary with the initial dryness and the amount and distribution of the rainfall, and with the degree to which the land is kept free of growing vegetation.

On shallow soil types where the development of roots or the storage of water is limited by underlying shale, caliche, or other more or less impervious material, and on shallow soils underlain with gravel, summer tillage is neither advisable nor practical. The shallowness of the soil will of itself limit the amount of water that can be stored. After a soil has been filled to its carrying capacity it is obvious that no amount of cultivation will increase its water content. Crops grown on such shallow soils are largely dependent on seasonal rains.

The use of summer tillage varies widely in the Great Plains. The lower the average rainfall and the less crops are diversified, the more frequently it is used. Where diversified cropping is practiced and especially under the higher range of rainfall, annual cropping tends to replace summer tillage, except for special purposes. In western Nebraska corn or some intertilled crop is frequently grown as a preparation for winter wheat.

In the question of tillage the time element has been found to be very important. There is a time when labor can be expended most efficiently in the destruction of weeds or in the cultivation of a surface that is in danger of blowing. In this the agricultural engineer has made important contributions. The advent of big machinery not only reduced the cost of tillage, but enabled the farmer to meet in a much more effective manner the time element. Without large machinery dry farming as now practiced would not be possible.

Tillage will accomplish much to lessen drought damage. It cannot completely overcome it. The evidence shows that its greatest benefit is found in years when climatic conditions approach the normal. Unfavorable variations from normal, tend to crop failures; favorable variations tend toward good yields from all methods.

I have dealt at considerable length with the question of moisture storage because in the early years it seemed the most important problem of dry farming. Probably of equal importance with the question of moisture storage has been that of crop adaptation. Almost all of the crops grown in the Great Plains in the early part of the present century were from seed which was transported from more favorable agricultural conditions. The agronomists of the several states and the U. S. Dept. of Agriculture have contributed better adapted varieties of small grains, corn, and sorghums, without which the present development of the agriculture of the Great Plains could not have been attained. These crops have been developed either from the standpoint of withstanding drought or evading it. A number of the crops now being grown were made possible through importations from foreign countries. Notable among these is the introduction of hard red winter wheat, which paved the way for the large development that has taken place in the central Great Plains. Western Kansas and Nebraska are now important centers in winter wheat production. One western county in Nebraska has increased its winter wheat area from 362 acres in 1906 to more than 213,000 in 1931. Kherson oats, brought into Nebraska during Dr. T. L. Lyon's time in that state, have been the foundation for a considerable part of the oats grown, where earliness is especially desired. The introduction of a number of sorghums made possible the development of strains that have done much toward stabilizing the agriculture of the southern part of the area.

Over much of the area early maturity to escape the heat and drought of mid-summer was desired in the small grains. In some crops the ripening period has been advanced as much as 10 days. The sorghums have been developed to increase their natural re-

sistance to drought, and in a number of cases to increase their earliness. Earliness and resistance have been obtained in the dry-land corn. It resembles but little the show corn of the recognized corn belt. The stalk is shorter and less leafy. The ear is smaller, with fewer rows of kernels. The kernels are short, rounded, and more flinty, but the corn matures and produces feed. In recent years adapted varieties of cotton have come into the southern section of the Plains as another cash crop.

The contributions along the line of crop adaptation are too numerous to admit of individual mention at this time. It should be noted that while the sorghums and corn are not so important as the small grains for cash crops, they have done much to stabilize the agriculture of the region. They have enabled the farmer to diversify and to keep livestock, thereby adding materially to his security. Furthermore, the land not suited to cropping can be utilized as pasture. In a very complete study of the question of crop rotations, the importance of rowed crops was well established. In some sections a cultivated crop has largely replaced fallow as a preparation for small grain.

Another important contribution to the production of crops that was generally applicable throughout the Plains was a study of the rate of seeding. It was definitely established that a lesser number of plants per given area was desirable in this section. This gives the individual plant a chance at a greater amount of moisture. The rate of seeding for the various crops has been determined by the workers in each state, to meet the local conditions. It has been found that seldom does the desirable rate exceed one-half of that of a humid area.

Are the farmers of the semi-arid area really better off than they were 20 to 30 years ago? The answer to this question is, Immensely so. This improvement, however, has been due to several factors, rather than to any single one or to any outstanding discovery. The area is still subject to the ravages of drought, but that fact is recognized. During the past quarter of a century there have been many failures, but there has been no general exodus from any section of the Plains. In my opinion the possibilities of agriculture in the Great Plains are as yet undetermined. Within the last quarter of a century the experiences of the farmers, the improved machinery, methods, and crops, and, lastly, but no less important, a reasonably satisfactory credit system, have pushed the margin of reasonable farming safety westward at least 150 miles. The lapse of time alone can reveal the permanency of the agriculture of any section. What will be the effect of 50 years more of farming in the Great Plains section?

Will it seriously reduce the fertility of the soil, or bring about danger from blowing? The question of maintenance of the organic and nitrogen content of the soil is a problem that will doubtless be considered by the agronomists of the not far distant future.

Can the margin of safety be pushed further westward? We do not have an infallible measuring stick, but feel that there is a limit beyond which reasonable safety does not now obtain. Just beyond that limit the soil still is attractive in the good years, but also beyond that limit there is being re-enacted today, though on a minor scale, many of the tragedies of the latter part of the last century. Probably the only reason why there is not a more or less general exodus from those sections is the fact that credit has been established. Even today there are sections in the plains where the sustenance for the coming winter and the seed for the coming harvest must be entirely dependent on credit. Perhaps a comprehensive national policy of land utilization would remove this land from production until the demand for food would warrant its reinstatement.

For their part in the development of the Great Plains the agronomists may feel professionally proud. They have established firmly in the minds of the farmers a fairly true picture of the climatic and soil limitations. They have determined more accurately than ever before the movement of soil moisture from its first impact on the surface to its final return to the atmosphere, and have related this knowledge to the tillage and cropping practices of the farmer. They have assisted in separating the false from the true in the several theories of dry farming. They have furnished more adapted strains of grain and forage crops developed especially to meet the exacting conditions of the Plains region.

As my co-worker, W. P. Snyder, of North Platte, Nebraska, who has spent his entire active life in the Great Plains, recently said,

"There is ample proof that these things have been accomplished. No longer does the farmer credit the optimist's theory of a changing climate. Weeds are no longer permitted to sap the moisture from the soil before the crop is planted. Very frequent surface tillage and very deep tillage no longer command the farmer's attention. His seed is home grown or introduced from regions of less favorable conditions. That this knowledge has made him conqueror of the land is evidenced by the fact that he is now building permanent homes where trees, shrubs, flowers and 'velvety lawns' play the same part as they play in developing beautiful farm homes in the presumably more favored regions of higher rainfall."

BREEDING EUROPEAN CORN BORER RESISTANT CORN[1]

A. R. MARSTON[2]

Investigations in 1930 at the Michigan State College Corn Borer Experimental Sub-Station at Monroe, Michigan, substantiate the belief that the use of Maize Amargo, when crossed with local Michigan corn varieties, will produce strains of corn resistant to attack by the European corn borer (*Pyrausta nubilalis*). Maize Amargo is a flint corn, the first seed of which was sent to the U. S. Dept. of Agriculture in 1921 by D. T. Bullock from Argentina. Mr. Bullock reported that in South America this variety of corn was strongly resistant to locust attack. He also stated in conversation with the writer in February, 1931, that it was his belief that seed for this variety of corn as grown in Argentina originally came from Hungary.

Maize Amargo proved resistant to the corn borer when tested at the Arlington, Mass., Experiment Station, in 1925, and also at the Monroe Station from 1926–30. At Monroe, this variety, when crossed with local Michigan varieties of corn, produced strains which were highly resistant to the corn borer. Some strains were free from attack by the borer, while adjacent strains were as high as 50% infested. A report on this work up to 1930 has already been published.[3]

In 1930, it was possible to test F_4 inbred strains of Maize Amargo crossed with Michigan corn varieties, and to compare the infestation of these with local corn crosses which had been inbred for an equal number of generations.[4] Although the general infestation was low in 1930, these F_4 inbred strains showed only 3 borers per 100 plants, while the local Michigan corn crosses had 12 borers per 100 plants. The F_4 inbreds of local corn X Maize Amargo with three borers per 100 plants had only one borer more than pure Maize Amargo, which had only two borers for the same number of plants (Table 1).

Table 1 shows that local non-inbred corn had an average of 19 borers to every 100 corn plants, over nine times that of pure Maize

[1]Contribution from the Farm Crops Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 64 (N. S.). Received for publication April 20, 1931.

[2]Agronomist, Michigan State College Corn Borer Sub-station, Monroe, Mich.

[3]MARSTON, A. R., and DIBBLE, C. B. Investigation of corn borer control at Monroe, Michigan. Mich. Agr. Exp. Sta. Spec. Bul. 204. 1930.

[4]C. B. DIBBLE of the Entomology Section of the Monroe Experimental Sub-Station supervised the collecting of the entomological data presented in this article.

Amargo and over six times that of the F_4 inbreds of local corn X Maize Amargo. A comparison of the F_3 generation of local corn X Maize Amargo with the F_4 shows 50% fewer borers per 100 corn plants in the F_4 generation. On the other hand, the F_4 inbred strains of local Michigan corn crosses show a 20% increase of borers per 100 plants over those of the F_3 generation.

TABLE 1.—*The number of corn borers per 100 corn plants, 1930.*

Strains	No. of plants	No. of corn borers	No. borers per 100 plants
Maize Amargo (corn borer resistant)	250	4	2
F_4 inbreds (local corn X Maize Amargo)	6,632	203	3
F_3 inbreds (local corn X Maize Amargo)	12,419	705	6
F_3 inbreds (local corn X local corn)	4,649	455	10
F_4 inbreds (local corn X local corn)	4,624	543	12
Check (non-inbred local corn)	16,482	3,136	19

The F_3 inbreds of the local corn crosses shown in Tables 1, 2, and 3 of this article were selected from strains having a low borer infestation in the F_2 generation. A similar selection was made in the F_3 generation of these local corn crosses, and only the inbred strains from plats having a low infestation were tested in the F_4 generation. Regardless of the borer infestation in the F_2 inbred strains of local corn X Maize Amargo, all strains were tested in the F_3 generation. From these F_3 inbred strains, selections were made for the

TABLE 2.—*Comparison of strains of corn on basis of plats without borers, 1930 tests.*

Strains	No. of plats	No. of plats without borers	Plats without borers %
Check (non-inbred local corn)	376	10	3
F_3 inbreds (local corn X local corn)	127	24	19
F_4 inbreds (local corn X local corn)	126	25	20
F_3 inbreds (local corn X Maize Amargo)	289	66	23
Maize Amargo (corn borer resistant)	10	6	60
F_4 inbreds (local corn X Maize Amargo)	282	171	61

first time, and only strains appearing to lack borer infestation at the time of pollination were inbred. However, when the final infestation count was made, at harvest time, some plats which appeared to be free from borers at the time of pollination had a few borers. Nevertheless, all the inbred strains obtained in these F_3 generation plats were tested in the F_4 generation. Each inbred strain was tested in a separate plat.

The comparisons in Table 2 show definitely that a significant increase in the number of borer-resistant plats was obtained from the F_3 to the F_4 generation of local corn X Maize Amargo when the strains tested in the F_4 generation had been selected by inbreeding only in the F_3 plats which lacked borer infestation at the time of pollination (Fig. 1). However, this method of selection in the local corn crosses did not give any greater number of strains without borers in the F_4 generation than in the F_3.

FIG. 1.—*Right,* Golden Glow X Maize Amargo, F_4 inbred, non-infested during F_3 and F_4 generations; *Center,* check (native Michigan corn), 38% infested; *Left,* Golden Glow X Maize Amargo, F_4 inbred, 30% infested.

As some strains may be resistant to the borer, even though they carry a few borers, it was thought advisable to compare the strains which carried two or more borers with those having fewer than two (Table 3).

The results shown in Table 3 check very closely with those in Table 1 where the number of borers per 100 plants in each strain was given. A comparison of the F_3 and F_4 inbreds of local corn X Maize Amargo showed a 24% decrease in the number of strains of the F_4 generation which had two or more borers. On the other hand, in the case of the local corn crosses there was a 3% increase of plats with two or more borers each in the F_4 generation as compared with the F_3.

TABLE 3.—*Comparison of strains of corn on basis of plats having two or more borers per plat, 1930.*

Strains	No. of plats	No. of plats with 2 or more borers	Plats with 2 or more borers %
Maize Amargo (corn borer resistant)	10	None	None
F_4 inbreds (local corn X Maize Amargo)	282	50	18
F_3 inbreds (local corn X Maize Amargo)	289	123	42
F_3 inbreds (local corn X local corn)	127	85	67
F_4 inbreds (local corn X local corn)	126	89	70
Check (non-inbred local corn)	376	348	93

The reduction from 93% in the local corn to 67% and 70%, respectively, in the F_3 and F_4 inbreds of local corn crosses, as shown in

Table 3, is possibly due to a lack of vigor caused by the inbreeding and not due to any inherent resistant characteristic (Fig. 2). Although a lack of vigor was expected in the inbreds of the local corn X Maize Amargo, as a whole they appeared more vigorous when planted than the inbreds of crosses of local corn varieties. However, the local corn X Maize Amargo, although more vigorous than strains of Michigan corn crossed and inbred for the same number of generations, had decidedly fewer borers per 100 plants, a greater number of plats without borers, and a fewer number of plats with more than two borers per plat.

FIG. 2.—*Left*, hybrid (single cross of F_3 inbreds Duncan X Maize Amargo) with a trace of corn borer work but without borers; *Right*, check (native Michigan corn), 48% infested, with 16 borers per 100 corn plants

It has been suggested that the apparent resistance of local Michigan corn X Maize Amargo might be due to the late-maturing characteristic of Maize Amargo, which normally is late in maturity and entirely unadapted to this region. However, crosses with other late-maturing varieties when tested proved to lack resistance and reacted to the borer in the same manner as did local corn crosses. For instance, Cuzco corn, another late-maturing South American type, was crossed with Michigan varieties of corn but did not produce strains that were resistant to the borer (Table 4).

TABLE 4.—*Number of corn borers per 100 plants in various crosses.*

Strains	No. of plants	No. of borers	No. of borers per 100 plants
F_3 Polar Dent X Maize Amargo	2,342	102	4
F_3 Polar Dent X Cuzco	387	39	10
F_3 local corn X local corn	4,649	455	10

Table 4 shows that Polar Dent crossed with Maize Amargo and inbred to the F_3 generation had only 4 borers per 100 plants, whereas the same generation of Polar Dent x Cuzco had 10 borers per

100 plants when inbred for the same length of time and did not differ from the local corn crosses in number of borers. It would appear, therefore, that the resistance of Maize Amargo cannot be attributed to its lateness and unadaptability. On the other hand, it appears to be due to genetic differences rather than any peculiarities of growth or the more obvious anatomical or physiological differences.

INHERITANCE IN A WHEAT CROSS BETWEEN RIDIT AND A SEGREGATE OF FEDERATION X SEVIER (14-85)[1]

GEORGE STEWART[2]

The primary purpose of this cross, Ridit X 14-85, was to combine the bunt resistance of Ridit with the higher yielding ability of the segregate from Federation X Sevier, known as 14-85. However, the contrasted characters other than smut afforded interesting genetic data which are here presented. Since a review of the literature pertaining to the characters studied in this cross has been made several times it is not included here.

DESCRIPTION OF PARENTS

Ridit.—Ridit has the winter habit of growth, is midtall, and has yellowish-white strong straw and white chaff. The spike is lax and fusiform with a few tip awns on the upper portion of the spike arbitrarily classed as awns 2 to make it parallel with previous classification at the Utah Station.[3] The grain is medium hard, midlong, and red in color. Ridit is highly resistant to the form or forms of bunt found in Utah, but it is not a satisfactory yielder.

14-85.—The segregate of Federation X Sevier, known by the number 14-85, has the spring habit, is somewhat shorter than Ridit, and has moderately strong straw. The chaff is dark bronze and the kernel is white and midlong. Its spike is compact or dense and fully awned. The segregate 14-85 is susceptible to bunt and subject to

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by Director, April 15, 1931. Received for publication April 21, 1931.

[2]Formerly Agronomist, Utah Agricultural Experiment Station; now Senior Forest Ecologist, U. S. Forest Service, Ogden, Utah. The author expresses his appreciation to R. W. Woodward for taking the data and for helping to prepare the manuscript for publication. Acknowledgment is also given to D. C. Tingey for assistance in growing the material.

[3]STEWART, G. Correlated inheritance in wheat. Jour. Agr. Res., 33: 1163–1192. 1926.

winterkilling when fall planted. It has good yielding ability as a spring wheat and is resistant to stem rust. As this strain is still in the plat test little is known of its quality for bread-making purposes or the extent of its agronomic adaptability. The contrasted plant characters here studied are shown in Table 1.

TABLE 1.—*Contrasted characters between Ridit and 14-85.*

Parent	Awns	Chaff color	Kernel color	Habit of growth	Resistance to bunt	Height of plant
Ridit...	Apically awned	White	Red	Winter	Highly resistant	Midtall
14-85...	Fully awned	Bronze	White	Spring	Susceptible	Somewhat shorter

EXPERIMENTAL PROCEDURE

The cross between a pure line of Ridit and of 14-85 was made in the summer of 1927 at Newton, Utah, a few miles from the Utah Experiment Station. The F_1 generation was grown in 1928, the F_2 in 1929, and the F_3 in 1930. Segregation was studied in the F_2, but the breeding behavior of the F_2 plants was determined by a study of the respective F_3 progenies. Fig. 1 shows the parental types and the F_1.

Bronze chaff and red kernel color were dominant in F_1, while spike density and awns were intermediate. One vigorous F_1 plant was chosen to continue the experiment and 384 F_2 plants were obtained, 2 of which failed to produce offspring, leaving 382 F_3 progenies. Data on all the contrasted characters were taken and filed for later study. When a sufficient number of kernels was obtained from an F_2 plant to make three plantings of approximately 40 kernels each, they were so divided. Some plants furnished only two and a few plants furnished only one planting. A complete series was seeded for this genetic study; the next largest group was treated with smut and fall-sown; and the third set, consisting of 151 lines, was seeded in the spring. In all cases, the kernels were spaced 2 to 3 inches in the row with the rows a foot apart. Parent rows were grown side by side after every 10 progenies, making a total of 38 rows of each parent. One parent row of 14–85 was accidently destroyed, leaving 37 rows of this parent and 38 rows of Ridit to be used as a comparison on the breeding behavior of the measured characters in this cross. At maturity each row was harvested separately, properly labeled, tied, and transported to the laboratory for study. Soon after harvesting the material was classified and measured.

EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

After all data were recorded, studies were made of individual characters. Such characters as chaff color, awn development, growth habit, and color of kernel could be readily classified into homozygous or heterozygous progenies. Height of plant and spike density were classified by a definite measured figure for each plant in an F_3 progeny. The mean, the standard deviation, and the coefficient of variability were obtained for the measured characters. By this means the comparative sizes of these coefficients were used to determine whether segregation could be established. The mean of the F_3 progeny was used instead of the measurement of the individual F_2 plant from which the F_3 progeny was descended.

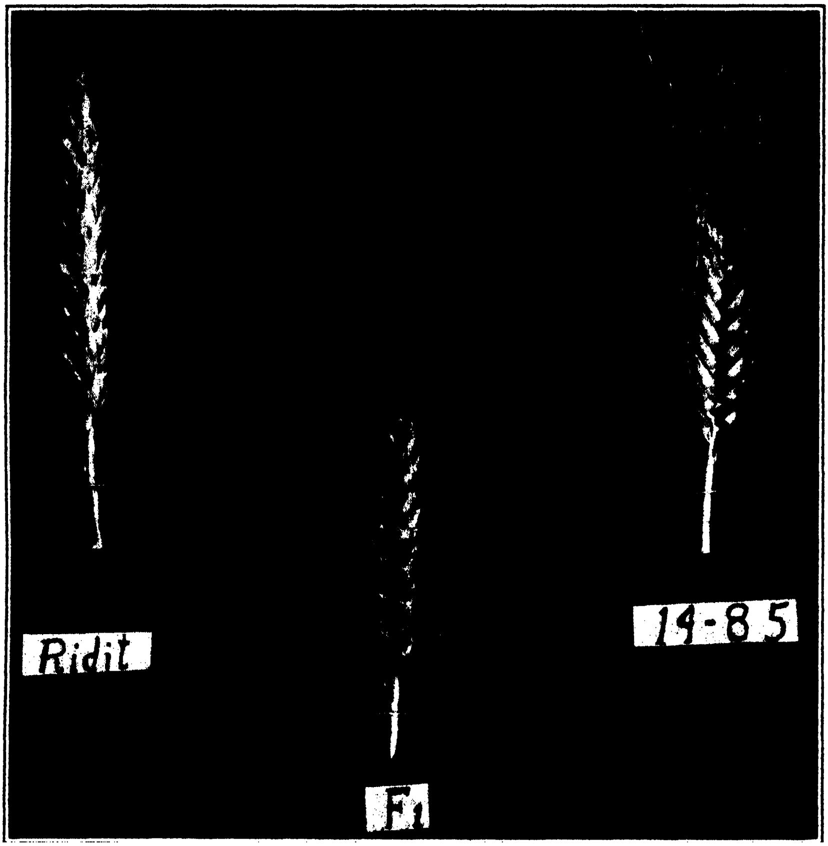

FIG. 1.—Heads from Ridit, 14–85, and the F_1 of the cross. Both awns and spike density are intermediate in the F_1.

Inheritance studies were made of glume color, awn development, kernel color, spike density, length of longest culm, and spring vs. winter habit of growth. A study of resistance to bunt was made as part of a separate project and is not reported here.

GLUME COLOR

Of the 382 F_3 progenies which matured seed, 98 were homozygous for bronze glumes, 193 were heterozygous, and 91 were homozygous for white chaff. In the heterozygous progenies a blending of color from white to dark bronze was observed. The data suggest a one-factor difference in the parents, and when compared to a 1:2:1 goodness of fit, X^2 = 0.298 and P = 0.8819. Table 2 shows the observed and calculated numbers in each class.

TABLE 2.—*Goodness of fit for three groups of F_3 progenies compared to a 1:2:1 ratio for glume color.*

Class	Calculated	Observed	$\frac{(O-C)^2}{C}$
Homozygous bronze	95.5	98	.065
Heterozygous	191	193	.021
Homozygous white	95.5	91	.212
		X^2 = 0.298	P = 0.8819

AWN CLASSES

The 14-85 parent was fully awned, while the Ridit parent had a few short apical awns classified arbitrarily as awns 2 to fit in with a numbering system previously adopted. The F_1 contained awns somewhat more vigorous than Ridit and were classified for convenience as awns 2.

TABLE 3.—*Closeness of fit of three awn classes when compared to 1:2:1 ratio.*

Class	Calculated	Observed	$\frac{(O-C)^2}{C}$
Homozygous awns 2	95.5	100	.212
Heterozygous	191	194	.047
Homozygous awns 4	95.5	88	.589
		X^2 = .848	P = 0.6664

In order to simplify working with awns and describing them, they have been grouped into classes as follows: Fully-awned condition, as awn class 4; short apical awns, as awn class 2; awnless with no awn development except an occasional beak on the apex, as awn class 1; and a group with some long apical awns and with short awns extending well down the spike, as awn class 3.

Fig. 2 shows the parental types, the F_1, and the three awn classes found in the F_3 progenies. In F_3, 100 progenies were homozygous for awns 2, 194 were heterozygous, and 88 were homozygous for awn class 4. Intermediates in the heterozygous progenies resembled the

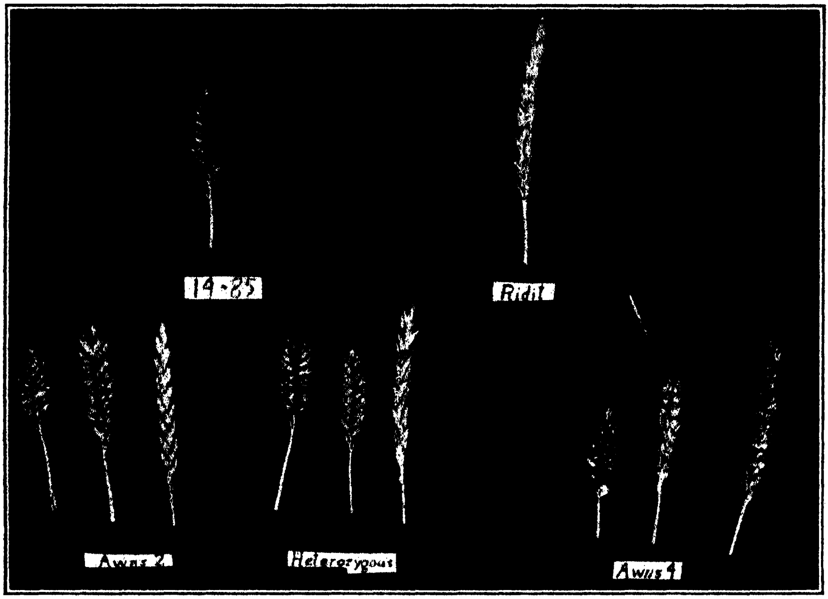

FIG. 2.—Types of awns found in the parents and F_3 progenies of this cross. A greater awn development was observed on the lax spikes.

F_1. A single-factor difference was suggested, and a goodness of fit compared to a 1:2:1 ratio in which $X^2 = 0.848$ and $P = 0.664$ is shown in Table 3.

KERNEL COLOR

Red color of kernel was dominant in the F_1. In the F_2, 357 plants contained red kernels with 27 showing white kernels. A 15:1 ratio is suggested and a close fit obtained, as indicated below:

	Red	White	Dev.	P. E.	Dev./P. E.	Odds
Calculated	360	24	—	—	—	—
Observed	357	27	3	3.2	.94	1:1

Further evidence for the suggested two-factor difference was observed in the F_3 data. The 27 plants containing white kernels in F_2 bred true in F_3, and of the 357 F_2 plants showing red kernels, 161 progenies bred true for red, 97 segregated in a ratio of 15 red to 1

white, 97 segregated in a 3 red to 1 white ratio, and 2 failed to produce offspring.

Table 4 compares the data obtained to the suggested 7:4:4:1 ratio, in which P = 0.7933. No accumulative effect of the two

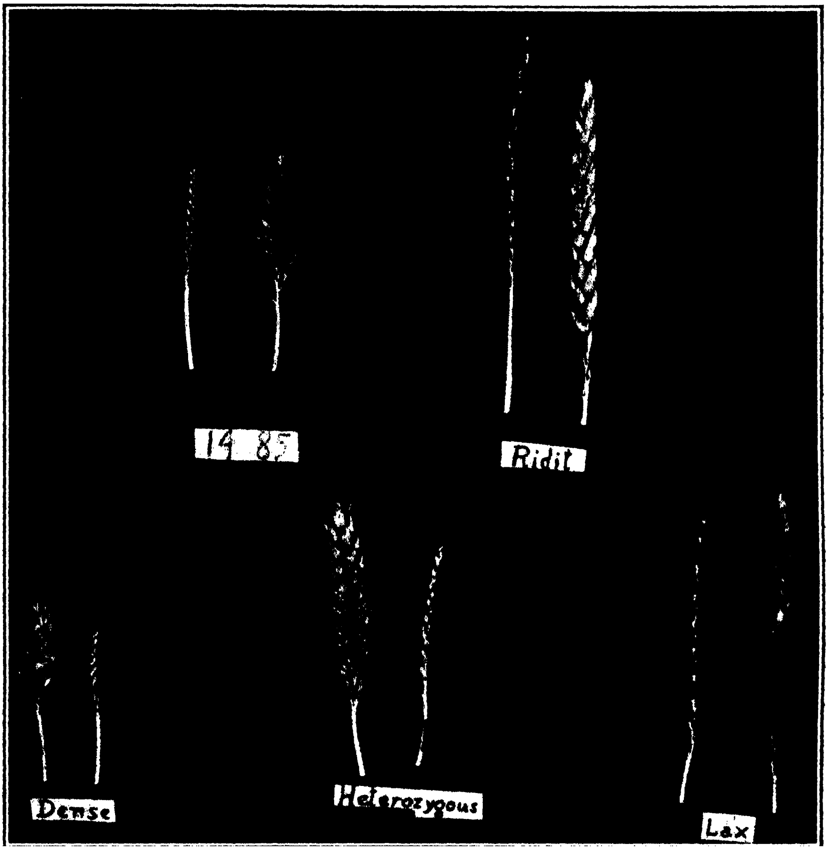

FIG. 3.—Parental types and F_3 progenies for three spike density groups.

factors for red kernels could be detected by inspection in the F_3 progenies.

TABLE 4.—*Goodness of fit of four groups as to grain color on a two-factor difference (7:4:4:1 ratio).*

Class	Calculated	Observed	$\frac{(O-C)^2}{C}$
Homozygous red	167	161	.215
Segregating 15:1	95.5	97	.023
Segregating 3:1	95.5	97	.023
Homozygous white	24	27	.375
		$X^2 = 0.636$	P = 0.8737

SPIKE DENSITY

A careful measurement was taken of 10 internodes from the central portion of a leading spike from each F_3 plant. The mean obtained from each F_3 progeny was used as a measure of the parent F_2 plant. The F_2 plants were also treated in the same manner and an attempt made to determine segregation. Fig. 3 shows the spike density classes found in this cross. Overlapping occurred between the homozygous dense and heterozygous groups, but a close approximation to a 3:1 ratio was observed in F_2 when the merging groups were considered against the rather distinct group of homozygous lax. When the F_2 and F_3 data were correlated a correlation coefficient of 0.9306 ± .005 was obtained. The extreme dense spikes of F_2, from 13 to 17 mm, bred true in F_3; and the group from 25 to 31 mm in F_2 segregated in F_3. A break in the distribution of F_2 plants for spike density occurred between 31 and 34 mm, beyond which all plants bred homozygous lax in F_3 (Table 5). By using the mean, as was done in the F_3 progenies, the range of variability in the various classes was somewhat reduced. Table 6 shows segregation as determined by the spike density classes and coefficients of variability. Clear-cut segregation thus appears with 95 progenies closely resembling the 14-85 parent, 186 progenies heterozygous, and 101 progenies similar to Ridit. A simple-factor difference is suggested and a fit of P = 0.8230 obtained when compared to a 1:2:1 ratio, as shown in Table 7.

TABLE 5.—*Distribution of F_2 plants and F_3 progenies for spike density.*

Class	Length of 10 rachis internode classes (mm)																						
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58
F_2 Distribution																							
Total F_2	3	23	49	57	55	49	18	11	7	1	2	1	2	7	13	13	16	25	14	2	1	5	
Homozygous dense	3	22	41	19	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Heterozygous	—	1	8	38	52	48	18	11	7	1	—	—	—	—	—	—	—	—	—	—	—	—	
Homozygous lax	—	—	—	—	—	—	—	—	—	—	2	1	2	7	13	13	16	25	14	2	1	5	
F_3 Distribution																							
Homozygous dense	—	4	39	44	7	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heterozygous	—	—	—	—	2	4	25	41	55	41	14	3	1	—	—	—	—	—	—	—	—	—	—
Homozygous lax	—	—	—	—	—	—	—	—	—	—	—	—	—	2	6	19	31	26	15	1	1	—	—

The distribution of the parent rows and of the F_3 progenies is shown in percentage of total plants and according to classes for 10 rachis internodes in Fig. 4. Recovery of the parental types in the

homozygous progenies was found with a shifting in both directions. The extent of this transgressive segregation is shown in Table 8. The entire group of homozygous dense is 2.10 ± .246 mm more dense than the dense parent. The fact that this difference is 8.5 times the probable error makes it seem a really significant difference. When the 19 most dense progenies are compared with the dense parent, the difference is 4.06 ± .327 mm which is 12.4 times the probable error.

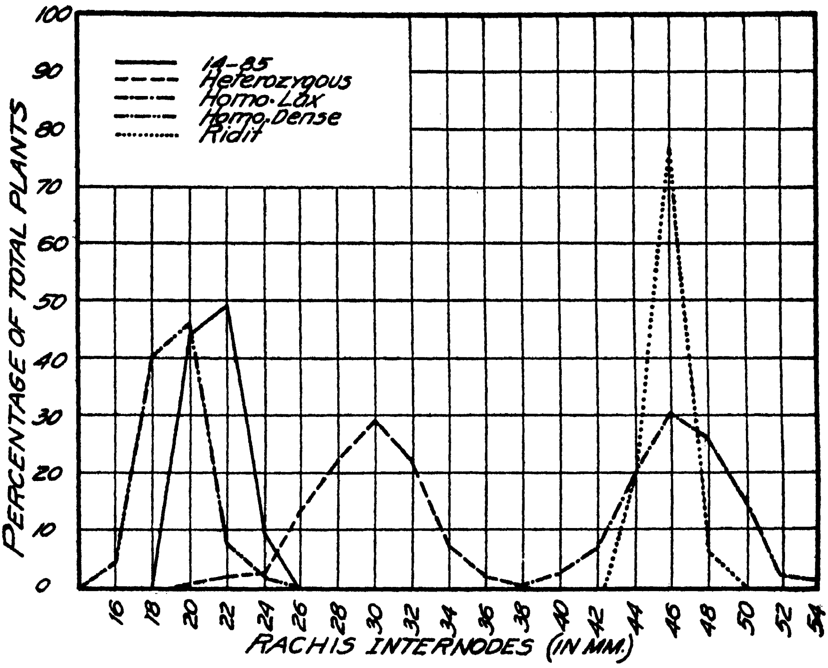

FIG. 4.—Spike density classes for Ridit, 14–85, and the three classes found in F_3. It is to be noted that a considerable number of the homozygous dense progenies are more dense than the dense parent, 14–85, and a somewhat similar group of the more lax homozygous progenies are more lax than the lax parent, Ridit. Calculations reported in the text showed these differences to be statistically significant.

The entire group of lax progenies is 1.63 ± .303 mm more lax than the lax parent, whereas the mean of the 19 most lax progenies is 4.46 ± .476 mm more lax than the lax parent. These differences are 5.4 and 9.4 times their respective probable errors.

There seems, therefore, to be strong evidence of a transgressive segregation of spike density which throws an appreciable group of dense progenies more dense than the dense parent and a similarly large group of lax progenies more lax than the lax parent.

TABLE 6.—*Mean spike-density and coefficient of variability (C.V.) classes of Ridit x 14-85 and of the three groups of F_3 progenies of their cross grouped separately and in combination.*

Parent or progeny	Spike density classes																				Total	C.V. classes
	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54		
14-85	—	—	4	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	5
	—	—	10	10	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	21	8
	—	—	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	11
	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	14
Total or mean				21.2																	37	8.90
Ridit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	14	1	—	—	—	17	2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	15	1	—	—	—	20	5
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	8
Total or mean	—	—	—	—	—	—	—	—	—	—	—	—				45.5					38	4.44
F_3 Progenies	—	—	1	—	—	—	—	—	—	—	—	—	—	—	6	3	9	2	—	—	21	2
	3	14	20	4	1	—	—	—	—	—	—	—	2	3	9	20	16	11	1	1	105	5
	1	9	19	3	—	—	—	—	—	—	—	—	—	3	3	4	—	2	—	—	44	8
	—	16	4	—	—	—	—	—	—	—	—	—	—	—	1	3	1	—	—	—	25	11
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	14
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	23
	—	—	—	—	—	1	—	1	—	—	1	—	—	—	—	—	—	—	—	—	3	26
	—	—	—	1	—	1	—	2	—	1	—	1	—	—	—	—	—	—	—	—	6	29
	—	—	—	—	1	2	3	5	4	4	—	—	—	—	—	—	—	—	—	—	19	32
	—	—	—	—	2	3	8	13	10	4	1	—	—	—	—	—	—	—	—	—	41	35
	—	—	—	1	1	2	12	15	13	4	1	—	—	—	—	—	—	—	—	—	49	38
	—	—	—	—	—	8	10	12	12	1	—	—	—	—	—	—	—	—	—	—	43	41
	—	—	—	—	—	6	7	7	1	—	—	—	—	—	—	—	—	—	—	—	21	44
	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	3	47
	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	50
Total or mean									31.6												382	21.9

TABLE 6.—*Continued.*

Parent or progeny	Spike density classes 16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	Total	C.V. classes
Homozygous lax	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	3	9	2	—	—	20	2
	—	—	—	—	—	—	—	—	—	—	—	—	2	3	9	20	16	11	1	1	63	5
	—	—	—	—	—	—	—	—	—	—	—	—	—	3	3	4	—	2	—	—	12	8
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	3	1	—	—	—	5	11
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	14
Total or mean													47.1								101	5.7
Homozygous dense	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2
	3	14	20	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42	5
	1	9	19	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32	8
	—	16	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	11
Total or mean	19.0																				95	7.67
Homozygous	—	—	—	—	—	1	—	1	—	—	1	—	—	—	—	—	—	—	—	—	3	26
	—	—	—	1	—	1	—	2	—	1	—	1	—	—	—	—	—	—	—	—	6	29
	—	—	—	—	1	2	3	5	4	4	—	—	—	—	—	—	—	—	—	—	19	32
	—	—	—	—	2	3	8	13	10	4	1	—	—	—	—	—	—	—	—	—	41	35
	—	—	—	1	1	2	12	15	13	4	1	—	—	—	—	—	—	—	—	—	49	38
	—	—	—	—	—	8	10	12	12	1	—	—	—	—	—	—	—	—	—	—	43	41
	—	—	—	—	—	6	7	7	1	—	—	—	—	—	—	—	—	—	—	—	21	44
	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	3	47
	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	50
Total or mean	—	—	29.7																		186	38.1

LENGTH OF LONGEST CULM

In order to obtain a measure for the length of longest culm, the roots of the pulled plants were placed firmly against a foot board perpendicular to the measuring board. Measurements were taken to the base of the spike on the longest culm of each plant. The mean of an F_3 progeny was used as the figure for an F_2 plant. The parental rows included after every 10 progenies were measured in the same fashion. The mean difference between the two parents was 7.1 cm, Ridit being 93.3 cm with a coefficient of variability (C. V.) of 6.2 and 14-85 being 86.2 cm with a coefficient of variability (C. V.) of 8.9. The 382 F_2 plants analyzed in F_3 had a mean of 89.2 cm for longest culm and a coefficient of variability (C. V.) of 7.6. Table 8 shows the distribution of the progenies as compared with the parent in which there is evidence of segregation but in which the segregating groups could be separated. In Fig. 5 the parental means and the progeny means are plotted in percentages.

TABLE 7.—*Goodness of fit of the three F_2 progeny groups for spike density when compared to a 1:2:1 ratio.*

Class	Calculated	Observed	$\frac{(O-C)^2}{C}$
Homozygous dense	95.5	95	.003
Heterozygous	191	186	.131
Homozygous lax	95.5	101	.316
		$X^2=0.450$	$P=0.8230$

TABLE 8.—*Mean of spike densities of homozygous dense group of progenies and of 19 extremely dense progenies in comparison with the dense parent and the same for the entire lax group and for 19 extremely lax progenies in comparison with the lax parent.*

Parent or progeny group	Mean spike density	Difference between group of progenies and similar parent	Dif./P.E.
14-85 (dense parent)	21.20±.227	——	—
Homozygous dense progenies	19.10±.095	2.10±.246	8.5
Homozygous lax progenies	47.19±.190	——	—
Ridit (lax parent)	45.56±.236	1.63±.303	5.4
19 extremely dense progenies	17.14±.216	4.06±.327	12.4
19 extremely lax progenies	50.02±.436	4.46±.476	9.4

WINTER HABIT OF GROWTH

Kernels from 151 F_2 plants were sown to study the inheritance of winter and spring habits. In the F_3, 50 progenies were homozygous for spring habit; 86 segregated for early, medium, and late spring types and for winter habit plants; and 15 were true for winter habit. In no case did the Ridit parent rows show any signs of heading nor

did the progenies homozygous for winter habit. An approximation to the 15:1 ratio was obtained when homozygous spring and heter-

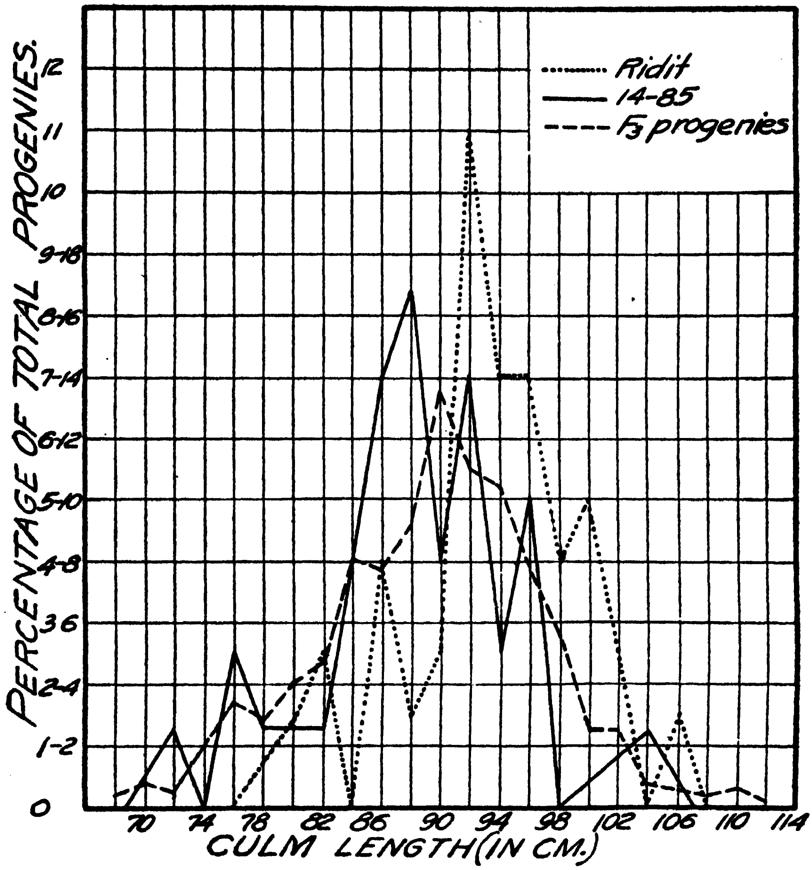

FIG. 5.—Distribution of 382 F_3 progenies in percentages for the various height classes and for Ridit and 14–85.

ozygous progenies were considered together against homozygous winter progenies, as indicated below:

Spring		Winter				
Calculated	Observed	Calculated	Observed	Dev.	P. E.	Dev./P.E.
141	136	10	15	5	201	2.49

It was somewhat difficult to analyze the segregation further than to say that a two-factor difference for habit of growth is suggested in this cross.

CORRELATIONS

The measured characters of this cross, length of longest culm and spike density, were correlated. The correlation coefficient (r) is .2521

± .0324 which is 7.7 times its probable error. The smallness of these constants do not furnish strong evidence of significant correlations between spike density and length of the longest culm.

Correlations were made between the Ridit and 14-85 parents for the length of longest culm and for spike density. When the spike density in Ridit and 14-85 were correlated r = + .0720 ± .110, whereas r = + .9568 ± .009 when the length of longest culm was correlated in the same manner. Spike density seems to be a very stable character and shows little soil heterogeneity, while length of the longest culm fluctuates widely and shows great heterogeneity as affecting height. These figures tend to corroborate the conclusions of distinct segregation for spike density and doubtful segregation for length of longest culm.

SUMMARY

The cross Ridit by a segregate of Federation X Sevier was made in order to combine economic characters of resistance to bunt with high yielding ability and rust resistance. A study of the genetic material was made and the results reported in this paper.

When sufficient seed was available in the F_2, three separate spaced plantings were made, *viz.*, one as a genetic study, one as a smut study, and a third for spring vs. winter growth habit.

A one-factor difference was found for glume color, P = .88.

The Ridit parent contained short apical awns, while the 14-85 parent was fully awned. A simple 1:2:1 ratio was obtained, P = .66.

Color of kernel suggested a two-factor difference in the F_2 with D/P.E. of 0.94. The expected 7:4:41 ratio was obtained in F_3, P = .87.

In spike density, homozygous progenies more dense than the dense parent and more lax than the lax parent were obtained. One major-factor difference in spike density was found, P = .82. The factorial explanation of the transgressive segregation was not found.

Length of longest culm as studied by the coefficient of variability and length of culm classes shows no separation of segregating groups.

A two-factor difference was suggested for spring vs. winter growth habit in which the D/P. E. = 2.49.

A high correlation was found between the spike density of the F_2 plants and the mean of the F_3 progenies in which r = + .9306 ± .005.

Parental rows were grown side by side after every 10 progenies in F_3 and a correlation between the 37 pairs for length of longest culm was high with r = + .9568 ± .009. When a similar correlation was made for spike density r = + .0720 ± .110. The stability of the spike density factors corroborates the findings with respect to transgressive segregation of spike density.

PROPOSED SOIL CLASSIFICATION OF THE ISLAND OF OAHU, HAWAIIAN ISLANDS[1]

T. J. DUNNEWALD[2]

As the analyses of Maxwell (1)[3] and later of Kelly (2) and Burgess (3) show, the soils of the Hawaiian Islands vary greatly in their chemical character and the influence of rainfall and temperature changes upon soil characteristics is marked within very short distances.

A rainfall map (Fig. 1) of Oahu Island after Ohrt (4) shows that the moisture supply ranges from 20 to 240 inches or more annually. The major part of the rainfall comes with the prevailing winds from the northeast and is dropped on the parallel mountain ranges of Koolau and Waianae which lie at right angles to the prevailing winds. Their average elevation is 2,600 to 2,800 feet with a few peaks rising to 4,000 feet.

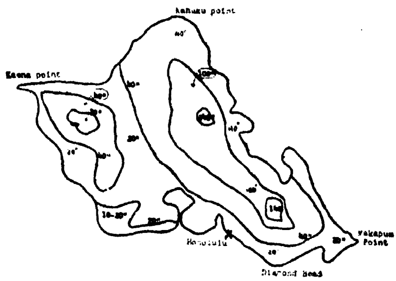

FIG. 1.—Rainfall map of the Island of Oahu, Hawaii.

The soils are prevailingly red or yellowish red except in spots of poor drainage where more organic matter has given the soil a darker brown or black color. Also, beginning at elevations of 1,200 to 2,500 feet, organic matter has accumulated under the influence of rainfall and cooler temperature and areas of soil with dark brown to black surface and red subsoil are found on the timbered or bushy mountain slopes. The parent soil material is all derived from lava of quite uniform character and varying in age. Beach sand and coral reefs are the parent material of small strips of soil along the sea coast. A few patches of saline or salty soils are observable along the marshes and fish ponds of the sea coast also.

Shrub and grass plains vegetation were characteristic of the drier parts of the Island. Larger timber is found at 100 inches rainfall and scrubby trees in some places with 20 to 30 inches rainfall. These last

[1]Contribution from the Department of Agronomy, University of Wyoming, Laramie, Wyo. Based on personal observations and soil samples collected by the author on the Island of Oahu, January 1 to 25, 1931. Published with the approval of the Dean and Director. Received for publication April 22, 1931.

[2]Assistant in Soil Investigations.

[3]Reference by number is to "Literature Cited," p. 983.

are mainly Algeroba forests and plantings introduced 50 to 100 years ago. A proposed classification of the soils of the Island is as follows:

	Rainfall, inches	Elevation, feet	pH	Crop
	Pedocals			
A. Lateritic soils which retain lime	0–25	0–300	7.0–9.0	Sugar
Podsolized soils				cane
Beach soils				Rice
Marsh soils				
Dune soils				Taro
Saline soils				
	Pedalfers			
B. Laterite soils which retain iron and alumina	25–400	300–1,300		Pineapples
Laterites (residual)	25–100	300–1,200	7.0–5.0	Coffee
Laterites (transported)				Bananas
Podsolized soils	100–200	1,200–3,000		Timber, ferns
Bog soils	200–400	3,000–4,000		Brush, reeds

A. The soils which retain lime are found in the low coastal areas where rainfall is less than 25 to 30 inches. The concentration of lime is evident in cracks between the lava blocks beneath the soil in various places along the south coast of the Island where roadway cuts reveal the deeper lava. Analyses by Kelly also show the lime content of some of these drier soils. Phosphorus and potassium are more available and silica is more soluble in these basic soils. Sugar cane is the main crop (5) on the uplands of the Pedocals.

Beach and marsh soils are largely flooded and used for rice, taro, and vegetable growing. The soils vary from porous coral sand to black or drab heavy clays carrying considerable amounts of organic matter. Some of the clays retain the salts from sea water and exhibit saline qualities such as deflocculation, resistance to drainage, etc. In a few places the coral sand has been drifted by wind into dunes and maintenance of a vegetative cover is difficult.

B. The soils which accumulate iron and alumina are prevailingly red in color below 1,200 and 1,500 feet elevation and exhibit characteristics of Laterite such as loss of silica and bases. With higher elevation and rainfall, the surface 6 to 24 inches of soil becomes reddish brown to nearly black in color due to accumulation of organic matter. In the lower parts of this zone, which bears heavy tropical vegetation, the organic matter merely coats the outside of the soil particles and, when pulverized, the black soil again assumes a reddish color. As one approaches 3,000 feet elevation, the dark grayish to

black color is permanent even when the soil is finely ground and the soil exhibits a more loamy or sandy texture than in the red zones lower down. This latter zone of soil lies at 3,000 to 5,000 feet elevation where the maximum rainfall occurs. Here the summit plateaus are swampy or muddy and densely forested with thick undergrowth of ferns and heather. This is the zone of bog soils and occurs mainly on other islands of the group such as Kauai, West Maui, and East Molokai. A small remnant (6) is reported on Mount Koala of the Waianae Range in southern Oahu Island.

Samples of the various horizons of three profiles were secured from densely timbered areas in three of these soil zones as follows: (a) Dry Algaroba forest, rainfall 10 to 25 inches; (b) intermediate moist forest, rainfall 100 to 200 inches; and (c) high mountain Koa forest, rainfall 200 to 400 inches. The profile descriptions briefly condensed are as follows:

Profile No. 1.—Virgin red clay loam. Scrubby Algaroba forest. Road cut on west side of Koko Head crater. Elevation 300 feet. Rainfall 25 inches. Forested at least 50 to 75 years.

A_0—4 inches friable reddish brown loam to silt loam.
B_0—4 to 12 inches red clay loam, prismatic, chunky.
B_1—12 to 20 inches, red clay loam (yellowish birdshot fragments).
C—20 to 40 inches, yellowish clay loam (yellowish birdshot fragments).

Profile No. 2.—Large Algaroba and Eucalyptus trees on Tantalus Mountain. Road cut in heavy timber, some trees 12 to 14 inches in diameter. Rainfall 120 to 140 inches. Forested 75 to 100 years.

A_0—0–6 inches, brown to dark brown silty clay loam. (The A horizon varies from 8 to 26 inches deep, average 12 to 14 inches.)
A_1—6 to 26 inches, black clay loam to clay.
B—26 to 48 inches, reddish brown clay.
C—48 to 72 inches, yellowish brown loam to clay loam.

These dark soils become red or yellowish when ground and sieved (50 mesh).

Profile No. 3.—Fern and Koa forest, edge of Kileaua volcano on Hawaii Island. Rainfall 200 to 400 inches. Elevation 4,000 feet. Forested at least 100 years.

A_0—0 to 4 inches, dark brown loam or sandy loam.
B_0—4 to 5½ inches, compact brown loam.
B_1—5½ to 7 inches, compact grayish loam to clay loam.
C—8 to 40 inches, loose grayish brown sandy loam.

These soils did not change in color upon grinding.

PODSOLIC LATERITES

The podsolic process is characterized by removal of sesqui-oxides and the accumulation of silica in the surface horizon and of colloids

and clay particles in the subsoil. The podsolic process reaches its climax in moist cool conditions where organic matter is deposited on top of the soil under timber.

On the other hand, the lateritic process is characterized by removal of silica and accumulation of sesqui-oxides, and the more complete the process, the smaller is the silica-sesqui-oxide ratio. When lateritic soil becomes timbered, therefore, we have two opposing weathering processes at work, one tending to accumulate iron and aluminum sesqui-oxides and the other tending to remove them from the surface horizons and to carry them into the subsoil.

TABLE 1.—*Mechanical separates, Oahu soils.*

Horizon	Depth, inches	Fine clay, organic matter, %	Silt %	Very fine sand %	60-mesh fine sand %	0.5 mm medium sand %	Coarse 1 mm sand %
			Koko Head				
A	0–4	27.9	30.8	38.6	2.24	0.27	0.09
B_1	4–12	22.3	**38.7**	35.5	2.80	0.19	0.29
B_2	12–20	21.1	**41.7**	35.7	1.69	0.46	0.19
C	20–40	22.2	22.1	34.1	1.27	9.31	0.49
			Tantalus				
A_0	0–4	25.4	28.0	25.4	9.01	9.31	2.70
A_1	4–26, top	20.6	27.6	28.3	18.8	4.33	0.11
A_2	4–26, bottom	20.6	**32.7**	**34.2**	10.6	1.76	0.00
B	26–40	20.6	**34.8**	**31.1**	11.0	2.23	0.00
C	40–72	19.5	30.4	28.2	15.2	6.08	0.10
			Fern Forest				
A	0–3	5.4	18.2	33.7	20.9	13.8	7.80
B_0	3–5	6.6	**19.6**	38.7	24.8	10.2	0.09
B_1	5–7	6.6	**53.6**	20.5	12.3	2.8	4.09
C	8–24	2.0	22.0	39.7	25.11	10.9	0.00

MECHANICAL ANALYSES

A mechanical analysis (Table 1) of the horizons of the three profiles selected show the tendency for finer particles to leave the surface and accumulate in the B horizon under podsolic influence.

The removed particles seem to be the silt rather than the finest clay. This fact agrees with analysis of laterites by Senstius (7), who agrees that the clay particles should be concentrated in the B horizon if podsolization is indicated.

Many of the coarser mechanical particles appeared to be conglomerations of fine particles which had not been split up by the ammonia used to deflocculate the soils at the beginning.

STAGES IN WEATHERING

Examination of the mechanical separates under the microscope showed considerable variation in color of particles. There appeared to be three general groups, *viz.*, clear particles, red and yellow coated particles, and black opaque particles. The approximate number of each is summarized in Table 2.

TABLE 2.—*Classification of particles according to color.*

Soil	Rainfall, inches	Appearance under microscope			Appearance to naked eye
		Red %	Black %	Colorless %	
Koko Head	25	75–90	5–20	1–4	All particles red
Tantalus	100	50–80	15–40	3–25	Only two coarsest groups red
Fern Forest	400	40–70	20–45	4–35	Only the coarsest sand group red

In the arid laterization the great proportion of soil particles appeared to be coated with red or reddish yellow iron. With higher rainfall (100 inches) the small particles obtained a coating of organic matter (8), also making them opaque under the microscope. With still greater rainfall, there were fewer red-yellow particles and more black and colorless particles. Here only the coarse sand particles were red to the naked eye, with all the finer groups having a black or bleached grayish black color.

A larger number of particles appeared red in color and fewer were clear in sodium carbonate solution than in strong hydrochloric acid solution. The stages in weathering of the soil particles seemed to include (a) clear particles, (b) particles coated with iron hydrate (yellow) or iron oxide (red), and (c) particles coated with organic matter (opaque or black). The smallest particles seemed to become coated with iron and organic matter first, followed by the larger particles.

CHEMICAL ANALYSES

Table 3 gives the chemical data. The soils were fused with sodium carbonate for analysis.

THE LATERITIC PROCESS

Judging by the SiO_2 sesqui-oxide ratios, the Tantalus soil is most highly lateritic. This process seems to reach its maximum in moist warm situations where maximum organic matter accumulates. It is less active in dry, warm (Koko Head) situations and in very moist slightly cooler (Fern Forest) situations.

THE PODSOLIC PROCESS

Judged by the removal of silica from the surface horizon, the podsolic process has been least active compared to the lateritic one, in the moist warm situation (Tantalus) and most active in the elevated cooler and very moist situations (Fern Forest) where sesqui-oxides also have accumulated in the B horizons.

TABLE 3.—*Chemical analyses, Oahu soils.*

Horizon	Loss on ignition %	SiO_2 %	Fe-Al oxides %	MnO %	CaO %	MgO %	Si-Fe ratio	pH
			Koko Head					
A	20.04	36.92	36.63	0.00	4.25	2.16	1.00	7.3
B_1	15.84	41.76	36.26	0.00	3.19	2.95	1.15	7.0
B_2	16.40	40.86	38.20	0.00	2.56	1.98	1.07	7.0
C	16.30	45.92	29.83	0.00	5.07	2.88	1.54	7.1
			Tantalus					
A_0	26.53	25.26	46.16	0.00	1.08	0.97	0.54	6.7
A_1	12.16	28.74	58.28	0.00	0.15	0.67	0.49	6.7
A_2	12.92	29.29	56.17	0.64	0.72	0.90	0.52	6.7
B	12.53	29.05	56.54	0.00	1.10	0.78	0.51	7.1
C	15.19	34.38	49.38	0.00	0.82	0.23	0.69	7.1
			Fern Forest					
A	10.73	52.81	31.43	5.14	3.64	1.39	1.68	6.5
B_0	9.06	47.12	37.33	7.17	4.10	2.39	1.26	6.7
B_1	2.09	50.08	41.57	7.03	4.66	1.60	1.20	6.7
C	2.20	50.20	40.07	6.02	5.13	2.40	1.25	6.7

BASES

The calcium content of the parent material seems to have been about 5% and the magnesium content about 2.5%. These have been largely removed in all horizons of the Tantalus soil at 100 inches rainfall. Why they have not been more extensively removed from the Fern Forest soil with 400 inches rainfall is difficult to explain unless the latter is much younger and less weathered than the Tantalus soil.

SUMMARY

1. The podsol process, which is essentially leaching by organic matter, occurs wherever tree growth covers soil or wherever organic matter is deposited on top of the soil even in tropical climates.

2. Lateritic soils become podsolized when covered with trees. The podsolic process is slower or weaker at 20 to 30 inches of rainfall, more rapid at 100 inches, and most active at 400 inches.

3. The lateritic process is due largely to high temperature but reaches a maximum where high temperature and rainfall are combined. The quartz grains first become coated with reddish iron and then by black organic matter. The advanced stages of laterization

seem to be marked by a greater number of coated grains rather than by any increased thickness of the coatings.

4. The SiO_2 sesqui-oxides ratio of laterites becomes narrowest under combined high rainfall and high temperature. The ratio is larger under arid conditions and under high rainfall combined with cooler temperatures.

5. Silica is retained less largely in the high lime-basic-arid laterites, and more so in the most acid, timbered, and most humid laterites of the higher elevations. The sesqui-oxides are lowest where the silica is highest, and *vice versa.*

6. No hard pan of iron salts is indicated in these soils except a slight tendency in the B horizon of the Fern Forest soil.

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ALFALFA SEED PRODUCTION STUDIES IN MICHIGAN[1]

E. E. DOWN[2]

Hardigan alfalfa, a winterhardy variety, developed by F. A. Spragg and introduced in 1920 by the Farm Crops Section of the Michigan Experiment Station, is demonstrating that, among the alfalfas, it is one of the best hay producers for Michigan. Hardigan has also yielded well in tests in New Jersey, Ohio, Illinois, Iowa, and other states. Comparative field trials in Michigan and elsewhere also are proving that Hardigan is an excellent seed producer. In two years of seed production trials carried on at Aberdeen, Idaho, on the edge of a Grimm stronghold, Hardigan produced an average yield of 422 pounds of seed per acre, while the Grimm seed yield was 159 pounds.[3]

[1]Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 66 (New Series). Received for publication April 23, 1931.

[2]Research Associate in Farm Crops. The writer wishes to express his appreciation to Dr. E. A. Bessey for helpful suggestions and criticisms rendered during the progress of these investigations.

[3]Data furnished the writer by H. W. Hulbert through correspondence.

Even though Hardigan alfalfa is an outstanding variety, alfalfa seed production lags in Michigan and the spread of Hardigan in this and adjoining states is comparatively slow. Immediate explanation of why the acreage of Hardigan is not increasing more rapidly lies in the fact that alfalfa forage in Michigan is usually more valuable than the seed that could be produced on the same area and that the production of forage is more dependable. Ten to 12 bushels of alfalfa seed per acre are sometimes obtained in certain sections of the West, *viz.*, Idaho and Utah, but 5 to 7 bushels per acre are an exceptional yield in Michigan. Three bushels per acre are a high average for the best seed-producing seasons, while during some seasons, like 1929 for example, many fields left for seed failed to produce enough to warrant harvesting the crop.

With conditions like these, it is not strange that a Michigan farmer is unwilling to take the risk of obtaining a small amount of alfalfa seed when an average of 2 to 3 tons per acre of good hay is practically assured. This is especially true in a dairy state where alfalfa hay is in great demand and often sells for $15 to $18 per ton.

The purpose of the investigations reported in this paper is to determine, if possible, some of the factors that influence the yield of alfalfa seed under Michigan conditions. Though information upon factors influencing alfalfa seed production is of vital importance to Michigan agriculture, the present knowledge is practically all based on deductions from general observations. However, several workers located in different parts of the United States and Canada have reported results of investigations based upon experiments covering the general subject of alfalfa seed production. Direct applications of their conclusions to Michigan may not be warranted because of differences in conditions. However, some of the findings of these investigators may have a bearing on the problem as it confronts the alfalfa seed industry of this state.

PREVIOUS INVESTIGATIONS

The difficulty of obtaining alfalfa seed consistently on the same field from year to year, or in the same locality during the same season, has long been recognized both by scientific workers and by growers. Both groups observed that the alfalfa plant responds differently under varied cultural and climatic conditions.

Brand and Westgate (1)[4] note that alfalfa plants growing alone produce more seed than crowded plants, probably because of the increased amount of available sunshine. They found that partial

[4]Reference by number is to "Literature Cited", p. 998.

shading of the alfalfa plant reduced the quantity of seed produced by plants not already receiving more than the optimum amount of sunlight.

Shoesmith (9) states that the conditions favoring alfalfa seed production in Michigan are rather dry, sunshiny weather from the beginning of bloom until maturity of seed, soils of light to medium fertility, and thin stands which allow the wind and sunlight to strike the sides of the plant as well as the tops.

Willis and Bopp (15) say that one factor of prime importance to successful production of alfalfa seed in South Dakota is that the available moisture supply be somewhat limited at the time when the plants are in bloom, and seed is forming.

Robbins (8) states, "Seed production is usually light in humid sections of the country. Moreover, too much irrigation water applied during the flowering period is detrimental to seed production."

Westgate, *et al.*, (14) say regarding the influence of temperature, "It has been found that relatively high temperatures are necessary during the period when the seed crop is setting."

The influence of some external means of pollinating the alfalfa flower has been recognized for many years. As stated by Piper, *et al.*, (7)

"According to Urban, the peculiar structure of the alfalfa flower by which it trips, or explodes when visited by certain insects was known in the time of Linnaeus." Robbins (8) explains, "Alfalfa possesses a mechanism for the explosive dispersal of its pollen. When the edges of the keel are spread apart, the staminal tube is released, and both the pistil and stamens snap up against the standard. The pollen is scattered in this process. The process is called 'tripping.'" Robbins (8) says further, "Alfalfa flowers are usually tripped by visiting insects, chiefly bumble bees and leaf-cutting bees (*Megachile*). The weight of an insect may be sufficient to cause a separation of the keel edges and consequently, 'tripping.' Usually, however, the separation is brought about by the protrusion of the insect's proboscis between edges of the keel. It has been observed that alfalfa flowers may be tripped without the visitation of insects. This is termed 'automatic' tripping. Humidity and temperature conditions are probable causative factors in automatic tripping."

Brand and Westgate (1) state, "Bumble bees (*Bombus* spp.) are generally believed to be the most efficient of all insects in setting off the explosive mechanism, and hence in bringing about pollination. Honey bees, though not nearly so effective as bumble bees, should not be under-rated in this connection." Westgate (13) observed over 5,000 visits of honey bees to alfalfa flowers. The flowers were tripped in only one case.

Piper, *et al.*, (7) observed, "That even when thrips are present in very large numbers the flowers very rarely develop into pods and seed unless tripped."

Several investigators have studied the influence of artificially tripping the alfalfa flower upon seed production.

Brand and Westgate (1) report the results of such a study, as follows: "In an experiment at Arlington Experimental Farm in which the method mentioned of exerting pressure successively over the whole plant was used, the yield of pods was increased 25.5 per cent over adjoining rows not thus treated. At Chico, California, an increase of 129 per cent in the number of pods resulted." Although the total amount of seed increased, the number of seeds per pod did not increase in proportion to the number of pods.

Piper, *et al.*, (7) report the results of artificially tripped alfalfa flowers in comparison with those allowed to develop normally at seven experiment stations located in different parts of the United States, namely, Pullman, Wash., in 1908, 1909, and 1910; Chico, Calif., in 1908 and 1909; Arlington Farm, Va., in 1908; Chinook and Havre, Mont., in 1909; and New London, Ohio, in 1912. They found that on the average 30.68% of the artificially tripped flowers produced pods, while on the same plant only 16.76% of the flowers allowed to develop normally produced pods.

Hay (4), working at Lethbridge, Alberta, Canada, reports that 9.48 and 5.49% of the flowers artificially tripped and those allowed to develop normally, respectively, formed seed pods. He concluded that lack of tripping is not the limiting factor to satisfactory setting of seed. Time of day when tripping was done did not influence setting of pods.

Carlson (2), working in Uintah Basin, Utah, an important alfalfa seed section, reports that 63.9% of the artificially tripped flowers and 37% of those flowers allowed to develop normally produced pods. In the latter group only 10.8% were found to have become tripped, leaving practically 26% that produced pods without tripping. However, he is the first to report any material setting of pods without tripping.

Southworth (12) reports, "When flowers were exposed to natural conditions and not tripped, slightly over one-quarter of the flowers developed pods, *viz.*, 26.4%. Hand tripping the exposed flowers increased the percentage of fertile flowers to 46.8."

In a very thorough and extensive investigation of the relation of atmospheric and soil moisture to seed production, Martin (6) found,

"That neither soil nor atmospheric moisture interfered with the development of the ovule. The setting of seed pods in alfalfa (*Medicago sativa*) is dependent upon the proper functioning of the pollen. Germination of the pollen depends upon a proper supply of moisture. If the water supply is either above or below a certain requirement, the pollen does not germinate. The water requirement for germination of the pollen depends upon a certain ratio between the moisture delivered by the stigma and the moisture of the air surrounding the stigma. It follows, therefore, that when the optimum supply of soil and atmospheric moisture for pollen germination is available, an increase in soil moisture, resulting in an increased moisture delivery of the stigma, or a change in the atmospheric moisture, disturbs the required moisture supply for germination and prevents fertilization."

The possibility of increasing alfalfa seed production by breeding varieties capable of producing more seed has been attempted by different plant breeders. The breeding work of Spragg and Down (10) culminated in one of the most successful introductions of this kind when Hardigan was introduced in 1920. Hardigan's success as a seed producer is apparently dependent upon its profuse flowering habits.

Southworth (12) has attempted to increase the automatic tripping habit of alfalfa by crossing *Medicago sativa* with *M. lupulina* (black medick) which normally has self-tripping flowers. He has carried the resulting hybrid through by successive stages to the seventh generation. Seed comparisons between F_6 hybrid plants and normal alfalfa plants grown under exposed conditions show that the hybrids produced more pods than normal alfalfa.

This review of the literature has revealed the importance of several of the factors influencing alfalfa seed production, and has emphasized the difficulty of assigning the cause for high yield to any single factor.

PRESENT INVESTIGATIONS

An experiment was planned in 1928 to study the influence of pollination upon alfalfa seed production. The data obtained resulted in an enlargement of the problem in 1929 to include other factors, such as, temperature, relative humidity, and the calculated moisture in the atmosphere, all taken at regular periods throughout the day.

The investigations of 1928 include a comparison under field conditions between the results obtained on pod and seed production from alfalfa flowers artificially tripped and those allowed to develop normally. The flowers were artificially tripped at three periods during the day, i.e., 9:00, 1:00, and 5:00 o'clock (eastern standard time). Racemes of flowers in about the same stage of development were

chosen for the artificial tripping study. All tripped flowers or unopened flowers were removed from each flower cluster. The remaining flowers were artificially tripped. Five racemes with approximately 20 flowers each were tripped at each period. Laboratory records were made of the number of pods and seeds that developed.

Artificial tripping was accomplished by pressing a pencil point against the keel of the flower, thus spreading it to allow the staminal tube and pistil to snap against the standard, scattering the pollen over the stigma.

The racemes used for the study of flowers allowed to develop normally were handled in the same way, except the opened, untripped flowers were allowed to develop normally without artificial tripping. Care was taken to keep from disturbing the untripped flowers when the tripped and unopened flowers were removed from these clusters. All flowers were then allowed to develop until harvested.

The same method of handling the flowers was followed in 1929, except the flowers were worked at hourly and sometimes at half-hourly intervals, when weather permitted. After June 29, the racemes became too small and too scarce to obtain valuable data each day.

A question arose in 1929 regarding the accuracy of the results obtained from flowers allowed to develop normally. Possibly the tripping was influenced by handling of these racemes, although great care was taken to prevent this. If the trigger of a gun is partly pulled, a further pull will easily complete the release of the hammer. Similarly, if the keel is partly opened by the handling treatment, further movement of such flowers by the wind could easily complete the release of the staminal tube and pistil, resulting in pollination. To determine whether or not this was taking place, a third group of racemes was chosen without any flowers tripped at the base. Unopened flowers located at the tip of the raceme were not removed. A count of the number of opened flowers was made.

After harvest, a laboratory count was made (beginning at the base of the rachis) of bracts (representing flower scars) and pods corresponding to the number of opened flowers recorded. The total number of pods found in this region was recorded together with the total number of seeds. These represent the number of pods and seeds that developed from the opened flowers uninfluenced by handling.

Temperature and relative humidity records were taken with a thermograph and hydrograph placed in a standard United States Weather Bureau instrument shelter. The instrument shelter was placed in the approximate center of the alfalfa plat and so arranged that the instru-

ments were on a level with a majority of the flowers. A check upon the accuracy of the recording instruments was made each half day, with a standard thermometer and psychrometer.

Populations were studied statistically and interpreted by Love's (5) modification of Student's table to determine whether the differences obtained could be accounted for by chance alone. Correlation coefficients were calculated by the diagonal method explained by Crum and Patton (3).

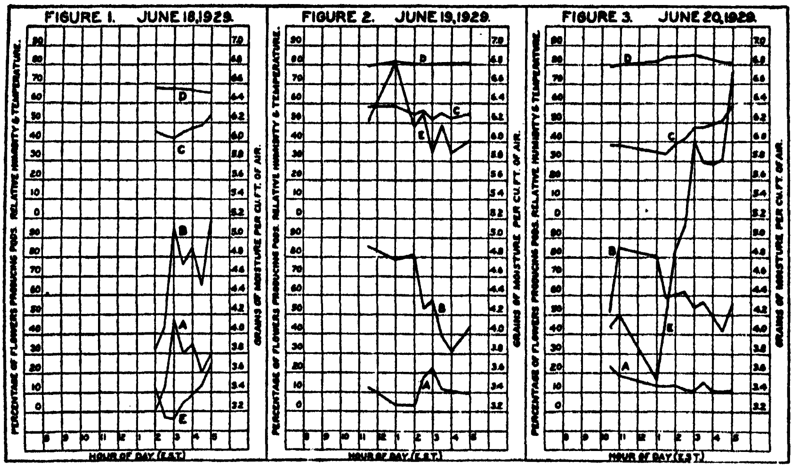
TABLE 1.—*Daily results assembled, showing pod and seed production from flowers in 1928.*

Time of day	Artifically tripped				
	No. flowers	No. pods	Total seeds	Flowers producing pods %	Ave. No. seeds per pod
9 A.M.	712	293	420	41.1	1.43
1 P.M.	746	383	648	51.3	1.69
5 P.M.	501	208	288	41.5	1.38
Total	1,959	884	1,356	—	—
Based on totals	—	—	—	45.1	1.53
Time of day	**Allowed to develop normally**				
	No. flowers	No. pods	Total seeds	Flowers producing pods %	Ave. No. seeds per pod
9 A.M.	750	93	161	12.4	1.73
1 P.M.	659	141	265	21.4	1.88
5 P.M.	408	54	86	13.2	1.59
Total	1,817	288	512	—	—
Based on totals	—	—	—	15.8	1.78

RESULTS

The data concerning pod and seed production for 1928 are assembled in Table 1. The data were collected on 8 days during the period beginning on July 6 and ending on July 19. Flowers artificially tripped set 2.85 times as many pods as those allowed to develop normally. The ratio between pods produced by the artificially tripped flowers and those allowed to develop normally is lowest at 1:00 o'clock, although this is the period of the day when the percentage of pods produced is the greatest, indicating that conditions in the middle of the day are most favorable to tripping and those processes influencing fertilization.

The pods from flowers allowed to develop normally had on the average 0.25 seed more per pod than those from flowers artificially tripped. The number of seeds per pod is in favor of flowers allowed to develop normally at all three periods of the day. The number of seeds per pod is slightly greater at 1:00 o'clock. Since each seed is the result of a separate fertilization, this is another indication that conditions at this period are more favorable to those processes influencing fertilization.

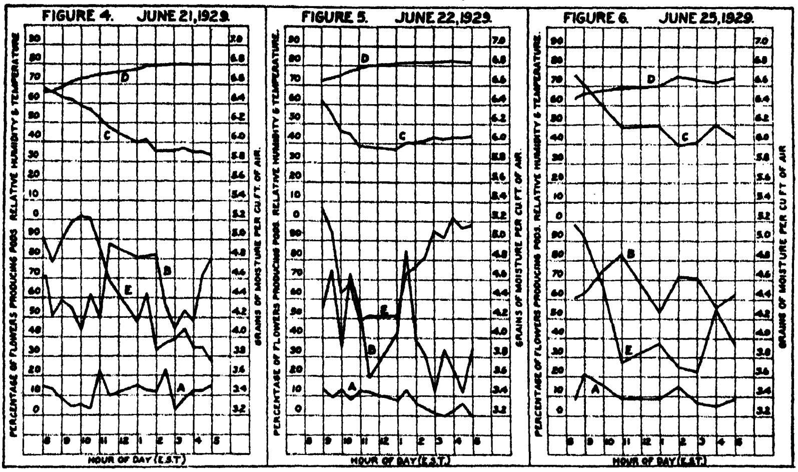


A, allowed to develop normally; B, artificially tripped; C, relative humidity; D, temperature; E, atmospheric moisture.

The daily and average results for pod production obtained in 1929, from flowers artificially tripped and those allowed to develop normally, are given in Figs. 1 to 9, inclusive, and in Fig. 10, respectively. They are assembled by half-day periods in Table 2. Statistical comparisons between the results classified under the headings of handled and not handled gave odds of 12 to 1 that these results are not significantly different, which shows that the handling of the flowers allowed to develop normally had no influence on their tripping. Therefore, the results from two populations are combined in all future comparisons.

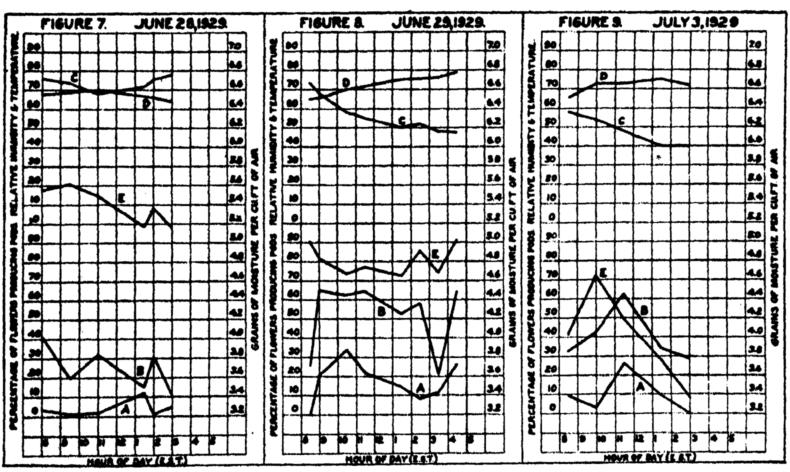
The results in Table 2 show that the flowers artificially tripped set pods much better than those allowed to develop normally for the corresponding half-day periods. This is also true in the case of the results obtained for corresponding periods of the same day, as shown by the daily graphs. That the setting of pods by both the artificially tripped flowers and those allowed to develop normally varies materially from day to day is shown by comparing the daily graphs.

Seed studies were materially influenced by the accidental cutting down of all the alfalfa plants about July 25, or some 22 days after



A, allowed to develop normally; B, artificially tripped; C, relative humidity; D, temperature; E, atmospheric moisture.

the last tagging. Examination of the cut plants showed that the formation of the pods was complete, but that seeds formed from



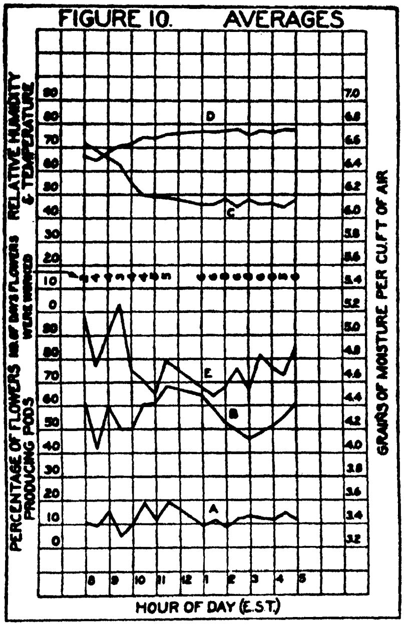
A, allowed to develop normally; B, artificially tripped; C, relative humidity; D, temperature; E, atmospheric moisture.

flowers tagged after June 25 were too immature to count accurately. For this reason the plan of statistically determining the relation of weather conditions to seed data had to be abandoned.

TABLE 2.—*Daily results assembled, showing pod production from flowers in 1929.*

Date	Artifically tripped			Allowed to develop normally								
				Handled			Not handled			Totals		
	No. of flowers	No. of pods	Flowers producing pods %	No. of flowers	No. of pods	Flowers producing pods %	No. of flowers	No. of pods	Flowers producing pods %	No. of flowers	No. of pods	Flowers producing pods %
June												
18 P.M.	512	365	71.3	575	141	24.5	125	10	8.0	700	151	21.6
19 A.M.	64	55	85.9	23	3	13.0	—	—	—	23	3	13.0
P.M.	450	226	50.2	433	50	11.5	238	35	14.7	671	85	12.7
20 A.M.	103	73	70.9	125	19	15.2	67	21	31.3	192	40	20.8
P.M.	777	465	59.8	734	86	11.7	432	57	13.2	1,166	143	12.3
21 A.M.	630	373	59.2	412	43	10.4	258	20	7.8	670	63	9.4
P.M.	754	519	68.8	742	86	11.6	391	56	14.3	1,133	142	12.5
22 A.M.	321	184	57.3	359	48	13.4	279	25	9.0	638	73	11.4
P.M.	539	187	34.7	560	26	4.6	357	18	5.0	917	44	4.8
25 A.M.	235	173	73.6	221	24	10.9	141	27	19.1	362	51	14.1
P.M.	366	228	62.3	312	33	10.6	189	16	8.5	501	49	9.8
28 A.M.	158	45	28.5	88	3	3.4	123	1	0.8	211	4	1.9
P.M.	178	31	17.4	178	5	2.8	142	15	10.6	320	20	6.3
29 A.M.	250	142	56.8	229	50	21.8	220	46	20.9	449	96	21.4
P.M.	235	118	50.2	188	27	14.4	215	36	16.7	403	63	15.6
July												
3 A.M.	228	112	49.1	176	24	13.6	217	28	12.9	393	52	13.2
P.M.	163	51	31.3	151	10	6.6	59	7	11.9	210	17	8.1
Total	5,963	3,347	—	—	—	—	—	—	—	8,959	1,096	—
Based on totals	—	—	56.1	—	—	—	—	—	—	—	—	12.2

As mentioned previously, total seed yields will be influenced by the number of seeds produced per pod. The results obtained from flowers artificially tripped and those allowed to develop normally are assembled by half-day periods in Table 3. The average numbers of seeds per pod are 2.35 and 1.99, respectively, for the two types of treatment. The difference of 0.36 seed per pod in favor of flowers artificially tripped is statistically significant. The odds that, under conditions prevailing in 1929, this difference is not due to chance are 132 to 1. The ratio between the total seed results when compared on a basis of the same number of flowers is 5.64 to 1 and the ratio of pods for the same period is 4.92 to 1.



A, allowed to develop normally; B, artificially tripped; C, relative humidity; D, temperature; E, atmospheric moisture.

The data obtained on seed pod production by artificially tripped flowers in Michigan compare very favorably with the data reported by Carlson (2) of Utah, working in a very favorable seed-producing section. The seed production obtained from flowers allowed to develop normally falls far below that obtained by Carlson.

INFLUENCE OF TIME OF DAY

The daily records for pod production in 1929 by artificially tripped flowers and those allowed to develop normally are shown graphically in Figs. 1 to 9, inclusive. The daily results averaged according to the hour of the day when they were obtained are shown in Fig. 10. The number of days involved in each average is also shown.

The daily records vary considerably from day to day. There is a strong tendency for these results to follow the trend of those obtained in 1928. The greatest pod production comes during the middle of the day, grading off in both directions to about the same point. In every case the results (for the same hour) of the artificially tripped flowers are well above those allowed to develop normally. Conditions

were apparently best for fertilization on June 18 and poorest on June 28. The amount of moisture in the atmosphere on June 18 (Fig. 1) was much less than on June 28 (Fig. 7).

TABLE 3.—*Daily results assembled, showing seed production from flowers in 1929.*

Date, June	Artifically tripped				Allowed to develop normally			
	No. of flowers	No. of pods	No. of seeds	Seeds per pod	No. of flowers	No. of pods	No. of seeds	Seeds per pod
18 P.M.	512	365	1,074	2.94	700	151	409	2.71
19 A.M.	64	55	163	2.96	23	3	11	3.66*
P.M.	450	226	484	2.14	671	85	170	2.00
20 A.M.	103	73	186	2.55	192	40	96	2.40
P.M.	777	465	1,115	2.40	1,166	143	296	2.06
21 A.M.	630	373	845	2.26	670	63	121	1.92
P.M.	754	519	1,354	2.61	1,133	142	311	2.19
22 A.M.	321	184	365	1.98	638	73	132	1.81
P.M.	539	187	343	1.83	917	44	71	1.61
25 A.M.	235	173	506	2.92	362	51	77	1.51
P.M.	366	228	438	1.92	501	49	82	1.67
Total....	4,687	2,793	6,710		6,950	841	1,765	
Average	—	—	—	2.35	—	—	—	1.99

*Results obtained during the morning of June 19 were omitted in the totals and in the calculations because the small number of pods and seeds obtained from the flowers allowed to develop normally gives an abnormal ratio. Results after June 25 were omitted because of unreliable seed counts.

The average results shown graphically in Fig. 10 bring out the trends during the entire period. The percentage of pods produced by artificially tripped flowers is comparatively low in the morning, increases until 11:30, decreases until about 3:00 o'clock, and then increases again. The percentage of pods produced is 42.1 at 8:30; 68.9 at 11:30; 46.4 at 3:00; and 60.9 at 5:00 o'clock. The irregularities in the graph during the morning would undoubtedly be smoothed out with more determinations. Results at 8:00 o'clock were obtained on two days only, June 21 and 28. Seventy-two per cent of the flowers artificially tripped at this hour on June 21 produced pods. This figure was responsible for pulling the average percentage up to 62.7. Probably data from several days would place the average percentage below that for 8:30. Heavy dews prevented the obtaining of more data at 8:00 a. m.

The trend of the graph for the flowers allowed to develop normally is somewhat like that for those artificially tripped, although not as smooth. The percentage of flowers producing pods was highest at 11:00 o'clock and lowest at 9:30. The general course of both these graphs indicates that conditions are most favorable for those processes influencing pod production just before midday. This does not

necessarily mean that conditions are best for tripping, but possibly a greater percentage of the flowers that actually do trip set pods.

INFLUENCE OF ATMOSPHERIC CONDITIONS

Temperature.—Reference has been made to the possible influence of temperature on alfalfa seed production. Though it is not possible for temperature to have any effect upon pollination of the artificially tripped flowers, it is possible for it to influence fertilization and, thereby, pod and seed production. Possibly the amount of tripping could be materially changed by the atmospheric temperature, since it would affect the transpiration of the alfalfa plant, and the balance between moisture intake and outgo may in turn regulate tripping.

TABLE 4.—*Correlation values between percentage of flowers producing pods and certain atmospheric conditions.*

Atmospheric factor	Percentage of flowers producing pods		
	8:00 to 5:00	8:00 to 1:00	1:30 to 5:00
Artificially tripped			
Temperature	$-.00\pm.07$	$+.20\pm.10$	$-.03\pm.08$
Relative humidity	$-.23\pm.07$	$-.26\pm.10$	$-.36\pm.08$
Grains moisture per cu. ft. of air	$-.25\pm.07$	$-.39\pm.09$	$-.32\pm.09$
Allowed to develop normally			
Temperature	$-.16\pm.07$	$+.02\pm.10$	$-.30\pm.08$
Relative humidity	$-.11\pm.07$	$-.18\pm.11$	$-.04\pm.09$
Grains moisture per cu. ft. of air	$-.20\pm.07$	$-.29\pm.10$	$-.30\pm.08$

The percentage of flowers producing pods and the hourly atmospheric records are shown in Figs. 1 to 9, inclusive, and the averages are given in Fig. 10. A study of these graphs shows that there is no apparent association between temperature and percentage of flowers producing pods.

The correlation coefficients were calculated for the entire day, 8:00 a. m. to 5 p. m., and for the two parts of it, 8 a. m. to 1 p. m. and 1:30 p. m. to 5 p. m. The correlation values are given in Table 4. They are all too small to be considered significant with one possible exception. A coefficient of $-.30\pm.08$ obtained with flowers allowed to develop normally may indicate that high temperatures have a slight negative influence upon tripping during the afternoon. Since a similar relationship was not found for the artificially tripped flowers, it may be that conditions favoring ultimate fertilization are not influenced so much by temperature as is tripping.

The author recognizes the possible fallacy that may arise when calculating correlation coefficients between the results obtained with

flowers allowed to develop normally and atmospheric factors. The atmospheric factors are taken at definite hours of the day and correlated with the results from these flowers, with the assumption that they tripped then, while the tripping may not have taken place until several hours later.

Relative humidity.—The general discussion concerning the possible influence of temperature on alfalfa seed production applies equally well to relative humidity. The data on relative humidity and its relation to seed production are shown in the same tables and figures as the temperature records.

The graph for any specific day usually covers a much larger range than the temperature graph for the same day. On certain days, like June 20, fairly strong negative relationships seem to exist between relative humidity and conditions favoring the setting of pods. When the relative humidity rises during the afternoon the percentage of pods produced by artificially tripped flowers decreases until 4:30. A similar influence on tripping seems to have existed during the afternoon of June 18, but as a whole the eye is able to detect little relationship between relative humidity and setting of pods.

The average results, Fig. 10, seem to show decided opposite trends between relative humidity and the percentage of pods produced by artificially tripped flowers in the forenoons, but little relationship is indicated during the afternoon. Little or no relationship is indicated between the results obtained from the flowers allowed to develop normally and relative humidity. The correlation coefficients bear out the last statement but contradict the former. The correlation coefficients are all negative indicating that the lower the relative humidity the more favorable are conditions for those processes which determine pod production.

Atmospheric moisture.—Neither temperature nor relative humidity are considered to be good measures of atmospheric conditions by themselves. The desirability of obtaining some measure of atmospheric conditions that considers both temperature and relative humidity seems quite apparent. The weight of moisture in a cubic foot of air involves both of these factors. The grains of moisture in a cubic foot of air for a given temperature and relative humidity were calculated from the theoretical values given in Table 73 of the Smithsonian Meteorological Tables (11). The data on atmospheric moistures are shown in the same tables and figures as the temperature and humidity records. The daily records of atmospheric moisture naturally follow those of relative humidity more closely than those of temperature.

A small variation in relative humidity and temperature will cause a big change in atmospheric moisture.

The daily graphs indicate that the relationship between atmospheric moisture and conditions favoring either the setting of pods or tripping is not strong, but in some cases a negative association is shown.

The correlation coefficients are larger as a whole than those previously studied, although none is large. They are all negative and indicate that the less moisture there is in the atmosphere, the greater the setting of pods and possibly the more the natural tripping.

DISCUSSION

The narrow range of temperature as found under field conditions may be partly responsible for the failure to obtain significant relationships between this factor and the setting of pods. Possibly with controlled atmospheric conditions significant relationships would be obtained, however, the temperatures found may normally be expected in Michigan when the first seasonal growth of alfalfa is blooming.

The variations in the setting of pods by the artificially tripped flowers on the different days and from hour to hour during the same day are not easily explained. This may be due to daily and hourly physiological variations within the plant, to environmental variations, or both, which influence the germination of the pollen grain, the growth of the pollen tube, or fertilization, and thereby the ultimate setting of pods.

A satisfactory setting of pods and seeds by flowers artificially tripped proves that the physiological conditions within the plant were favorable to the development of pollen grains and egg cells, also that the pollen grains and egg cells were reasonably morphologically good and fertile. Conditions would be equally favorable for the setting of pods by the flowers allowed to develop normally, therefore, the failure of these flowers to set pods proves that physiological conditions within the plant or environmental condition, or both, were not favorable to tripping.

SUMMARY

An experiment was begun in 1928 to study the influence of artificial tripping upon alfalfa seed production under Michigan conditions. The experiment was enlarged in 1929 to include the influences of such atmospheric factors as temperature, relative humidity and calculated moisture content upon pod and seed production.

In 1928, 45.1% of the flowers artificially tripped produced pods, while 15.8% of those allowed to develop normally set pods. The

pods from flowers artificially tripped and those from flowers allowed to develop normally contained 1.53 and 1.78 seeds per pod, respectively. At mid-day a greater percentage of the flowers produced pods than at either 9:00 or 5:00 o'clock, indicating that conditions are more favorable at that time to tripping and to those processes influencing the setting of pods.

In 1929, 56.1% of the flowers artificially tripped produced seed pods, while 12.2% of those allowed to develop normally set pods. The average number of seeds per pod was 2.35 for the artificially tripped flowers and 1.99 for those allowed to develop normally.

Pod production by the artificially tripped flowers varied materially according to the time of day when the flowers were tripped. On the average the percentage of pods increased as the day advanced until 11:00 o'clock, decreased until 3:00 o'clock, and then increased again.

Attempts to correlate atmospheric factors, such as temperature, relative humidity, and calculated moisture content, with the setting of pods failed to give any strong relationships. However, the consistent negative trend of the correlation values obtained between either relative humidity or calculated moisture and pod production tends to indicate that, as these atmospheric factors decrease, conditions become more favorable to those conditions favoring tripping and the setting of pods.

The data presented prove conclusively that lack of tripping was one of the chief factors limiting alfalfa seed production in Michigan during 1928-29.

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A MODIFICATION OF THE SAUNDERS' TEST FOR MEASURING "QUALITY" OF WHEATS FOR DIFFERENT PURPOSES[1]

G. H. CUTLER AND W. W. WORZELLA[2]

As a rule, "quality" in wheats is measured by a milling and baking test. This method does not lend itself to the needs of the plant breeder, since 5 pounds or more of wheat as a minimum are required. The plant breeder desires a test which, while reliable and quickly applied, will above all require but a few grams of seed. If possible, it should be suitable for testing the seed of individual plants. For years the plant breeder has hoped in vain that the cereal chemist would develop and perfect some test whereby an accurate indication of the "quality" of wheat could be obtained from a few grams of wheat. Several tests are available, but none of them are of themselves adequate nor do they lend themselves to the plant breeders' needs.

During the past few years the writers have endeavored to develop a method that will measure the characteristics which connote "quality" of wheats and thus serve to distinguish them on the basis of their suitability for different purposes. Among others, the Saunders' test (1)[3] was investigated and an attempt has been made to employ the principle embodied in this test when applied to small quantities of wheat meal. In doing so the technic has been greatly modified. Our results are so gratifying as to seem to merit a preliminary report at this time.

METHODS AND TECHNIC

Instead of refined flour as recommended in the Saunders' test wheat meal has been used exclusively. Raw wheat is ground to a medium fineness in a small mill. It was found that meal of medium fineness gave much more uniform results than either flour or fine meal. The coarser meal was not as satisfactory as the medium fine meal.

About 50 grams of sound dry normal wheat are ground so as to pass through a mesh of 1 mm in size.[4] The meal is thoroughly mixed and carefully sampled so that a uniform distribution of the finer and coarser particles is secured. The tests are made in triplicate

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[3]Reference by number is to "Literature Cited," p. 1009.

[4]The Wiley mill was used in these tests.

by weighing out three 10-gram samples, each of which is placed in a 150-cc glass beaker. In sampling, a spatula with upturned edges is used to insure uniform distribution of the finer and coarser particles. To each 10-gram sample of wheat meal is added 5.5 cc of about 10% yeast solution. The yeast solution is prepared by dissolving 10 grams of Fleischmann's yeast in 100 cc of distilled water maintained at 80° F. By means of a glass stirring rod the meal is then mixed into a mass.

After the meal has been mixed so that it will hold together, it is taken out of the beaker and placed in the palm of the hand and with the thumb it is kneaded for about 2 minutes, at least until it becomes a dough ball of medium-stiff consistency. The consistency of the dough is found to have an important bearing upon the end results. If too stiff and hard the "time" is very much shortened. Hence, care must be observed in this connection as it is only after continued practice that uniformity of results can be secured, considering the variation met with in the moisture absorption of different varieties of wheat. Since it is essential, however, to keep the amount of yeast solution constant for all samples, moisture is added when needed by inserting the ball in a beaker of distilled water. This is followed by further kneading until the right consistency is attained. The dough ball is then dropped into a 150-cc beaker containing 80 cc of distilled water, the temperature of which is maintained as nearly as possible at 80° F. If the temperature is allowed to vary widely from this point, the end results are greatly influenced. The time of immersion of the dough ball is recorded at once.

The beaker containing the dough ball is then placed under a glass bell jar which is equipped with an electric plate and bulb so that the operator can maintain a uniform temperature of 80° F in the bell jar. When large numbers of samples are being tested, it is found suitable to include as many as 30 in the jar at one time by placing the samples in tiers one above the other to fill the jar (Fig. 1). It has been found that two or more medium-sized bell jars can be operated by two attendants. This will accommodate upward of 60 samples.

Observations are made from time to time to note the behavior of the dough ball. It has been found that after about 20 minutes from immersion the dough ball will begin to show some changes in outward appearance. Gas bubbles will be observed to come out of the ball and pass to the surface of the water. As fermentation proceeds the ball becomes bouyant, rolls about, and rises to the surface of the water (Figs. 2 and 3, beaker No. 2), where it remains until eventual disintegration takes place. Sooner or later, depending on the quality

of the wheat being tested, the dough ball will give evidence of splitting or breaking apart (Figs. 2 and 3, beaker No. 3). When the dough thus begins to detach itself and falls to the bottom of the beaker, the time is again recorded. The "time" for each sample is thus obtained since "The Saunders' time of the flour (or wheat meal as adopted by the authors) is taken to be the number of minutes that elapse between the original immersion of the dough ball and the first fall of detached dough." This outlines in brief the technic of the wheat meal time test.

FIG. 1.—Bell jar with tiers of beakers containing dough balls and with thermometer inserted through the rubber stopper in the top.

EXPERIMENTAL

TESTS WITH SOFT WINTER WHEATS

After developing a suitable laboratory technic in which raw ground wheat meal of a proper fineness was substituted for flour and after temperature controls were worked out, experiments were undertaken to apply this wheat meal time test of "quality" to our known varieties of soft winter wheats.

The first experiment consisted in subjecting varieties of wheats grown at several outlying stations in Indiana. The stations are widely distributed in the state and represent a wide range of soil types, not to mention a variety of climatic conditions. The wheats tested were grown in the seasons of 1928–29 and 1929–30, respectively. Through an arrangement with the National Milling Company of Toledo, Ohio, milling and baking tests were made on these different lots according to standard methods. Hence, milling, chemical, and baking data on these wheats were secured.

The following varieties of wheat were used: Michikof, Kharkov, Purkof, Berkley Rock, Red Rock, 21–2–11, Michigan Amber, Fultz, Red Cross, Fulhio; Poole, American Banner, Trumbull, and Gladden. The results of the several tests are given in Table 1.

TABLE 1.—*Wheat meal time test, baking, chemical, and other data on seven varieties of winter wheat grown at different points in Indiana, 1929 and 1930.*

Variety	Class	No. of places grown		"Time" test, minutes		Absorption %		Loaf volume, cc		Protein %		Ave. yield per acre, bushels	
		1929	1930	1929	1930	1929	1930	1929	1930	1929	1930	1929	1930
Michikof	Hard Red Winter	5	5	213	299	60.0	55.9	1,818	1,789	9.55	9.76	16.73*	18.58
Purkof	Semi-hard Red Winter	7	9	194	246	58.5	55.5	1,881	1,857	8.28	9.43	25.60	22.52
21-2-11	Unknown	7	9	191	265	58.9	53.6	1,832	1,848	8.70	10.61	21.21	18.84
Mich. Amber	Soft Red Winter	7	9	163	168	56.6	55.2	1,851	1,720	8.10	9.32	22.10	19.22
Fultz	Soft Red Winter	6	9	133	146	56.9	53.4	1,950	1,844	8.43	9.31	23.73	18.39
Trumbull	Soft Red Winter	4	8	87	99	56.5	54.0	1,929	1,736	8.60	9.75	23.62	16.62
Gladden	Soft Red Winter	4	9	81	61	57.2	52.3	1,855	1,772	7.97	9.50	16.15	18.94

*The stands were very thin in Michikof greatly reducing the yields.

TABLE 2.—*Correlations between "time" and baking, chemical, and other characteristics of the same wheat varieties.*

Year	No. of varieties	Total No. of samples	Characteristics correlated with "time" and			
			Absorption	Protein (flour)	Loaf volume	Vitreous kernels
1928–29	8	45	.81 ±.0827	.60±.1517	.07±.24	.74±.107
1929–30	13	101	.60±.119	.49±.142	.56±.128	.48±.143
Average*	7	98	.916±.0411	.3613±.2216	—.0079±.2549	.8351 ±.0771

*The average was taken from the following seven varieties: Michikof, Purkof, 21-2-11, Michigan Amber, Fultz, Trumbull, Gladden, since these were grown both seasons at the same places.

Without attempting to discuss the data presented in Table 1, it will be noted that the "time" shows variation when applied to the same varieties in the two seasons of 1929 and 1930. This is to be ex-

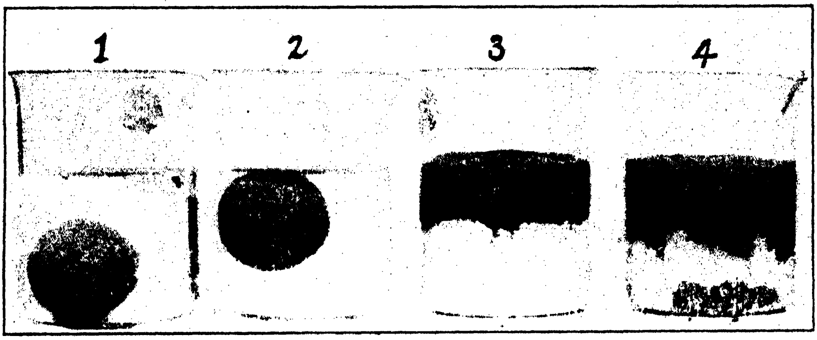

FIG. 2.—The dough ball from a hard spring wheat. 1, dough ball just immersed, when time is first recorded. 2, dough ball 20 to 30 minutes later, the surface of the ball is as smooth as when immersed. 3, the first piece of dough has just detached itself and is still hanging like a small tassel to the under surface, quite characteristic of the hard wheat dough ball. Time is again recorded. 4, Dough ball 3 or 4 hours later in a slow process of disintegration.

pected, especially when it is known that these seasons were different, the 1929 season favoring "softness" while the 1930 season favored "hardness" as indicated by the protein content. In keeping with

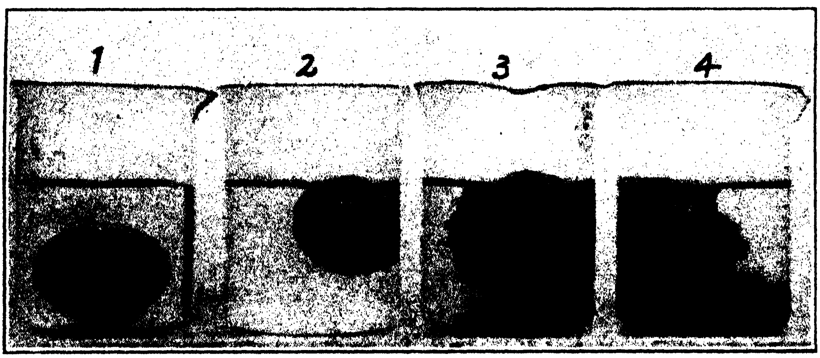

FIG. 3.—The dough ball from a semi-hard wheat. 1, Dough ball just immersed, when time is first recorded. 2, Dough ball 20 to 30 minutes later, the surface of the ball appearing rough and uneven. 3, The first piece of dough has just split off. Time is again recorded. 4, Dough ball 20 to 30 minutes later when it has disintegrated and completely fallen apart.

these differences, it should be noted that there were somewhat similar and corresponding differences in the baking and chemical data.

Simple correlations were determined according to the formula recommended by Hayes (2) and used by Bailey when only small numbers are available and are recorded in Table 2.

It will be observed that significant correlations appear to exist between "time" and absorption and vitreous kernels, respectively, as an average of 2 years' tests. These data do not show a correlation between "time" and loaf volume as might be expected. It seems possible that different results might be obtained if high-protein, strong-gluten wheats, especially when grown under dry land conditions, were tested.

In this connection it is of interest to note that baking and milling tests (3, 4) indicate the loaf volume of the variety Quality, a white wheat, to be as high or higher than that of Marquis, a hard spring wheat. If it is conceded that the wheat meal time test reveals the true "quality" of this variety (see Table 4), does it not suggest that loaf volume, though generally considered as a measure of "quality" of wheat desired for bread flour, is called in question? Manifestly it cannot be highly regarded as a satisfactory index for wheats used for other purposes.

The data presented in Table 3 support the correlations between the "time" test and the same characteristics.

TABLE 3.—*Correlations between absorption and other baking and chemical characteristics of the same wheat varieties.**

Year	No. of varieties	No. of tests	Characteristics correlated with absorption and		
			Protein (flour)	Loaf volume	Vitreous kernels
1928–29	8	45	.71±.118	.039±.238	.86±.064
1929–30	13	101	.1488±.1830	.0347±.1869	.7293±.0876

*Same varieties as used in Table 1.

TESTS WITH OTHER CLASSES OF WHEAT

In order to check further the technic which had been developed and applied to the varieties mentioned above, other wheats including different classes of known characteristics were subjected to the wheat meal time test. The most common varieties were secured from conditions where they are widely grown in the United States as well as in Saskatchewan, Canada.

The methods followed were the same as described above. The results (Table 4) represent an average of three tests for each variety.

In attempting to analyze these data, the reader must keep in mind that these wheats represent several classes and were grown under a

TABLE 4.—*The wheat meal time test applied to varieties of wheats representing different classes.*

Kind	Source	Peculiar characteristics of sample	Time, minutes
		Hard Spring Varieties	
Marquis	N. Dakota	Uniformly vitreous kernels	391
Marquis	Saskatchewan	Uniformly vitreous kernels	377
Marquis	Montana	Some mottled kernels but predominantly vitreous	360
Marquis	Wisconsin	Some mottled kernels but predominantly vitreous	312
Reward	Saskatchewan	Uniformly vitreous kernels	379
Reliance	Saskatchewan	Uniformly vitreous kernels	374
Reliance	N. Dakota	Uniformly vitreous kernels	316
Marquillo	N. Dakota	Uniformly vitreous kernels	366
Ceres	Saskatchewan	Uniformly vitreous kernels	323
Supreme	N. Dakota	Some mottled kernels but predominantly vitreous	248
Ruby	Montana	Some mottled kernels but predominantly vitreous	261
		Hard Red Winter Varieties	
Tenmarq	Kansas	Mottled and predominantly vitreous	364
Turkey Red	Nebraska	Mottled and predominantly vitreous	356
Kanred	Nebraska	Mottled and predominantly vitreous	334
Kanred	Kansas	Mottled and starchy	126
Malakof	Nebraska	Mottled and predominantly vitreous	302
Blackhull	Nebraska	Mottled and predominantly vitreous	300
Neb. No. 50	Nebraska	Mottled and somewhat starchy	253
Blackhull	Kansas	Mottled and predominantly vitreous	245
		Low-Protein Hard Varieties	
Turkey Red	Iowa	Mottled and predominantly starchy	158
Kanred	Iowa	Mottled and predominantly starchy	104
Iobred	Iowa	Mottled to vitreous	180
Ioturk	Iowa	Mottled to vitreous	181
Iowin	Iowa	Mottled to vitreous	149
Askof	Wisconsin	Mottled and predominantly starchy	192
Wis. Ped. No. 2	Wisconsin	Mottled and somewhat starchy	156
Ridit	Washington	Mottled and somewhat starchy	137
Federation	Washington	(White spring) mottled and predominantly starchy	164
		Soft Red Winter Varieties	
Mich. Wonder	Kansas	Mottled and predominantly starchy	117
Mich. Amber	Indiana	Mottled and predominantly starchy	168
Fultz	Indiana	Mottled and predominantly starchy	146
Fulhio	Indiana	Mottled and predominantly starchy	117
Trumbull	Indiana	Mottled and predominantly starchy	99
Currell	Kansas	Mottled and predominantly starchy	89
Fulcaster	Kansas	Mottled and predominantly starchy	81
Gladden	Indiana	Mottled and predominantly starchy	66
		White Varieties	
Baart	Washington	Mottled and predominantly starchy	144
Hybrid No. 123	Washington	Mottled and predominantly starchy	96
Albit	Washington	Mottled and predominantly starchy	61
Quality	N. Dakota	Uniformly vitreous kernels	90
Quality	Minnesota	Mottled to vitreous kernels	55
		Durum Varieties	
Kubanka	Montana	Some mottled but predominantly vitreous	84

wide range of soil and climate conditions. Certain generalizations, however, can be made which seem to agree well with known facts, *viz.*, the hard springs of high protein content and strong gluten record the longest "time;" the hard red winters of more or less similar characteristics stand next in point of "time;" the low-protein hards or "mixed" wheats of the corn belt stand next, though they tend to coincide and overlap with the strong soft red winters; the medium strong soft red winter varieties of the Middle West stand fourth in point of "time;" and finally, the weak gluten soft red winters and soft springs, the white wheats, and the durums fall together in the lowest "time" class.

TESTS OF MILLERS' SAMPLES

Believing that the wheat meal time test will serve a useful purpose in breeding soft winter wheats at Purdue, a number of the millers of the state were requested to send samples of soft wheat as grown and purchased from farmers and used in their trade. To date some 50 samples of wheat have come to hand. These have been subjected to the wheat meal time test and the results obtained from these and others that will be made from time to time will be used as a guide to the "quality" of wheat desired by our millers. The tests were made in triplicate according to the technic outlined above with the following results: 18 samples tested less than 100 minutes; 28 samples tested between 100 and 150 minutes; and 4 samples tested above 150 minutes.

Though this experiment is unfinished, it seems to point clearly to the fact that the wheat meal time test can render an important service to the wheat breeder. It seems capable of supplying him with an instrument by which he can ascertain the desiderata of quality in wheats peculiar to any given section; and of even greater importance, by the same "measuring stick" can be standardized all hybrids and selections that may be produced from time to time. Further, this can be done with small samples of wheat. Perhaps plants as early as the F_3 can be submitted to the time test.

This experiment, together with that reported in Table 4, strongly emphasizes that wheat breeders will be enabled to measure wheat quality in terms of time, each recognizing a "time category" to which the varieties of wheat he is interested in will conform. Indiana-grown wheats, for instance, doubtless fall into a fairly definite time category. This statement is borne out by past experience in this state. Saskatchewan hard springs, on the other hand, will fall into a distinclty higher time category, and similarly, time categories might

be set up for wheats grown in other sections, always in keeping with the typical wheats for the section and the requirements and purposes to which such wheats are put.

THE ACCURACY OF THE METHOD

The authors feel that the value of the wheat meal time test is not alone in its simplicity and accuracy but as well in the uniformity of the results secured. It is not fool-proof, however, and must be conducted according to prescribed methods if a high degree of satisfaction is to be achieved. That this is the case is shown by a series of tests which were carried out to measure the variability of results when conducted by a person of average skill. The tests were made on certified Trumbull, a soft red winter wheat widely grown in Indiana and Ohio. Some 180 tests were made. It required 20 hours to complete the tests. Variability was measured by the standard deviation and coefficient of variability, respectively, as follows:

$$
\begin{aligned}
\text{M} &= 81.9 \pm 0.398 \text{ minutes} \\
\text{S.D.} &= 7.92 \pm 0.282 \text{ minutes} \\
\text{C.V.} &= 9.69 \pm 0.345\%
\end{aligned}
$$

The results of this experiment are significant and indicate that the wheat meal time test can be operated with a high degree of uniformity.

There are several uncompleted problems left for further study which will occur to the reader. The possible use of the test by grain buyers, boards of trade, millers, milling and baking laboratories, etc., where a quick test is required, seems obvious. The writers plan to investigate these and other problems during the coming months. Especially do they desire to standardize an equipment suitable for making this test. Further investigations are under way to ascertain the minimum amount of wheat meal which will be required to make a satisfactory test. The ideal amount from the wheat breeder's point of view is as little, or less, than the amount produced by an individual plant.

SUMMARY

A series of experiments and data have been presented indicating that the "quality" of wheats may be measured by the wheat meal time test.

This test employs the principle embodied in the Saunders' test, but utilizes wheat meal instead of flour. The meal gives quicker, cleaner-cut, and more dependable results than when flour is used.

The "time" of the wheat meal time test shows a high positive correlation with absorption and vitreous kernels, respectively. The data presented did not show a correlation between "time" and loaf volume.

The test is expeditious, 30 samples of meal from soft winter wheats can be tested in triplicate by two persons in 8 to 10 hours.

Whereas most tests of "quality" require 5 to 10 pounds of wheat, the wheat meal time test needs only a few grams.

It is simple to operate, yet strict observance of details in procedure is essential for uniform results.

It is adapted for use of the wheat breeder but seems capable of being widely used.

Tests show high correlation between "time" and the "quality" of wheat desired for making flour for particular purposes. The wheats preferred for bread flour have a high "time" test, while the wheats preferred for pastry flour have a low "time" test.

The wheat meal time test as described has been adopted as a method of ascertaining the "quality" of new hybrids and selections in the soft red winter wheat breeding program in the Agronomy Department at Purdue University.

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REGISTRATION OF IMPROVED WHEAT VARIETIES, VI[1]

J. ALLEN CLARK[2]

Five previous reports present the registration of 267 wheat varieties. In 1929,[3] three varieties were registered and the previous articles cited. Last year[4] two varieties were registered.

Varieties approved for registration this year are as follows:

Varietal name	Registration No.
Gasta	268
Cheyenne	269
Komar	270

The origin and performance of these varieties are given as follows:

GASTA, REG. NO. 268

Gasta (Ga. No. P 303, C. I. No. 11398) was produced as a pure-line selection from Purplestraw at the Georgia Agricultural Experiment Station, Experiment, Georgia. The selection was made in 1921 and the new variety has been in nursery experiments (six series, three rod rows, center row cut for yield) since 1924. It is similar to Purplestraw except for having a higher yield and resistant in field tests to strains of loose smut present at Experiment, Ga. About 100 bushels of this wheat were distributed to farmers in the state this fall and it is being further increased for a larger distribution next year. The yields from the experiments, furnished by R. P. Bledsoe, the breeder and applicant, are given in Table 1.

CHEYENNE, REG. NO. 269

Cheyenne (Nebraska No. 50, C. I. No. 8885) was produced as a pure-line selection from Crimean (C. I. No. 1435) at the Nebraska Agricultural Experiment Station, Lincoln, Nebr. The selection was made in 1922 and the new variety included in plat experiments for 4 years at Lincoln, Nebr. Cheyenne differs from Crimean or Turkey

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 2, 1931.

[2]Senior Agronomist, Wheat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; member of the 1931 Committee on Varietal Standardization and Registration of the American Society of Agronomy charged with the registration of wheat varieties.

[3]CLARK, J. A., PARKER, J. H., and WALDRON, L. R. Registration of improved varieties, IV. Jour. Amer. Soc. Agron., 21:1172–1174. 1929.

[4]CLARK, J. A. Registration of improved wheat varieties, V. Jour. Amer. Soc. Agron., 22:1041–1042. 1930.

TABLE 1.—*Comparative yield data of Gasta and four other varieties of soft red winter wheat grown in nursery experiments at the Georgia Agricultural Experiment Station, Experiment, Ga., 1924–31.*

Variety	Yield in bushels per acre									
	1924	1925	1926	1927	1928	1929	1930	1931	Average	Percentage of Purplestraw
Gasta (new)	29.0	31.9	55.7	26.3	16.9	33.5	37.3	43.3	34.2	115.5
Redhart*	16.1	31.5	50.5	27.3	16.4	17.8	27.7	50.5	29.7	100.3
Purplestraw (standard)	27.5	26.7	45.2	22.3	18.7	24.6	32.7	39.4	29.6	100.0
Fulcaster (Dietz) (standard)	22.4	31.8	45.4	22.4	17.9	25.6	31.4	37.5	29.3	99.0
Red May (Early Red May)	22.2	28.4	25.1	22.9	13.5	29.6	35.8	40.5	27.3	92.2

*Not a registered variety.

in having more erect culms and heads, stiffer straw, greater resistance to shattering, and higher yields. The yields from the experiments furnished by T. A. Kiesselbach, breeder and applicant, are shown in Table 2.

TABLE 2.—*Comparative yield data of Cheyenne and four other hard red winter wheats grown in plat experiments at the Nebraska Agricultural Experiment Station, Lincoln, Nebr., 1928–31.*

Variety	Yield in bushels per acre					
	1928	1929	1930	1931	Average	Percentage of Crimean
Cheyenne (new)	24.6	39.0	47.4	48.0	39.8	105.9
Crimean* (parent)	26.6	35.9	41.0	46.8	37.6	100.0
Nebraska No. 60 (standard)	27.1	38.8	38.6	44.7	37.3	99.2
Kharkof*	22.4	35.8	43.9	45.7	37.0	98.4
Kanred (standard)	23.9	35.3	40.1	46.7	36.5	97.1

*Not registered varieties.

KOMAR, REG. NO. 270

Komar (N. D. Ns. No. 1656.84, C. I. No. 8004) was produced from a hybrid between Marquis (female) and Kota (male). The cross was made in 1918 by L. R. Waldron, plant breeder, North Dakota Agricultural Experiment Station. The selection from which Komar descended was made in 1923.

Komar is bearded and has white glabrous glumes, beaks 2 to 3 mm long, and midlong, hard red kernels. It differs from Ceres in

being more resistant to stem rust and a higher yielder, but has slightly weaker straw. Komar has been extensively tested at experiment stations in the spring wheat district and has an excellent performance record. In Iowa, it has shown best adapted. Application for the registration of this wheat was made by the breeder, L. R. Waldron, based on Iowa data obtained by L. C. Burnett. Seed of the variety was increased by the Farm Crops Section of the Iowa Agricultural Experiment Station and first distributed in 1930 for growing in Iowa. The comparative yield data upon which registration is based are shown in Table 3.

TABLE 3.—*Comparative yield data of Komar and five other varieties of hard red spring wheat grown in plat experiments at experiment stations in Iowa, 1927–31.*

Variety	Yield in bushels per acre						
	1927*	1928†	1929†	1930‡	1931§	Average	Percentage of Marquis
Komar (new)	27.0	25.3	34.7	26.7	31.4	29.0	137.4
Progress (standard)	17.0	27.1	31.9	25.2	28.7	26.0	123.2
Ceres (standard)	20.0	23.1	26.6	26.7	27.8	24.8	117.5
Garnet (standard)	20.0	25.8	31.4	16.6	23.7	23.5	111.4
Java (standard)	17.0	22.9	27.2	16.5	26.9	22.1	104.7
Marquis (standard)	12.0	28.4	31.4	14.1	19.4	21.1	100.0

*Mason City.
†Ames and Mason City.
‡Ames, Mason City, and Belmond.
§Ames and Kenawha.

Further information on Komar is given under its number, 1656.84, in North Dakota Agricultural Experiment Station Bul. 200, 1926.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, V[1]

T. R. STANTON[2]

The last record of registered improved varieties of oats was published in 1929.[3] No varieties were registered in 1930. The two improved varieties of spring oats mentioned below were approved for registration in 1931:

Group and Varietal Name	Registration No.
Early gray:	
Columbia	78
Early red:	
Franklin	79

The descriptions and performance records of these varieties, on which approval for registration is based, are summarized in this article for the information and benefit of those interested in producing more and better oats per acre by the use of superior varieties.

COLUMBIA, REG. NO. 78

Columbia (C. I. No. 2820) originated as an "off type" plant selection from Fulghum, made at the Missouri Agricultural Experiment Station, Columbia, Mo., by L. J. Stadler in 1920. It was subsequently tested and first distributed to farmers by that station in 1930. The application for registration was submitted by Roy T. Kirkpatrick. The superior characters of Columbia are a very erect habit of early growth, early maturity, and higher acre yield, especially for medium and late dates of seeding. The following rather complete description was submitted with the application:

The Columbia oat is an early maturing strain resembling Burt more than typical Fulghum from which it was selected. In general appearance Columbia is similar to Burt, though the plants are distinctly taller and more uniform and the heads are longer and distinctly more erect. Columbia is erect in early growth in contrast to Fulghum and Red Rustproof.

The grain of Columbia is medium large and much better filled than that of Burt, though not usually so plump as that of Fulghum.

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication December 2, 1931.

[2]Senior Agronomist in charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Member of the 1931 Committee on Varietal Standardization and Registration responsible for the registration of oat varieties.

[3]STANTON, T. R., GAINES, E. F., and LOVE, H. H. Registration of varieties and strains of oats, IV. Jour. Amer. Soc. Agron., 21: 1175-1180. 1929.

It is usually awnless though occasional awns are found. The color of the grain is a distinctive feature of the variety. It is gray with conspicuous light veins, resembling somewhat the variety Winter Turf but clearly distinguishable from any other spring-sown variety. The basal joint and basal hairs conspicuous in Burt and Red Rustproof are absent or inconspicuous in Columbia. Under average growing conditions in Missouri the weight per bushel and the percentage of kernel are as high in Columbia as in Fulghum, though especially favorable growing conditions produce a heavier grain in Fulghum than in Columbia.

The variety has been tested for 8 years in both replicated nursery rows and field plats at Columbia. The annual and average acre yields of Columbia as compared with those of standard varieties are shown in Table 1.

TABLE 1.—*Annual and average acre yields of Columbia and four other varieties of oats grown at the Agricultural Experiment Station, Columbia, Mo., for the years indicated.*

Variety	Mo. sta. No.	Yield in bushels per acre						Average
		1926	1927	1928	1929	1930	1931	
Columbia	0375	55.2	64.8	50.4	41.2	75.3	55.1	57.0
Fulghum (standard)	065	45.9	69.2	45.6	39.2	67.1	48.2	52.5
Burt	015	49.4	66.8	41.1	37.6	69.8	48.4	52.2
Kherson (Sel.)	0955	53.9	57.4	48.3	29.8	73.7	47.8	51.8
Red Rustproof (Red Texas Sel.)	0432	50.2	61.4	50.4	31.0	67.8	48.2	51.5

Acre yields of Columbia and five other varieties of oats grown on outlying experiment stations in Missouri in 1931 are shown in Table 2.

TABLE 2.—*Acre yields of Columbia and five other oat varieties grown at Columbia and seven other points in Missouri in 1931.*

Location of test	Varieties and acre yields in bushels					
	Columbia	Kanota	Fulghum	Albion	Kherson	Silvermine
Columbia	73.1	68.4	60.3	70.8	59.9	41.6
Grain Valley	63.0	64.1	62.7	50.0	46.9	26.1
Maryville	38.8	41.0	37.2	39.2	36.3	25.5
Elsberry	95.3	96.7	99.5	85.6	80.1	33.7
Shelbyville	52.1	45.4	42.7	53.9	52.1	32.9
Green Ridge	32.3	29.0	27.0	24.9	22.3	16.1
Golden City	18.1	14.8	16.2	17.1	17.7	8.4
Stark City	16.8	17.6	18.8	18.4	16.3	7.4
Average	48.7	47.1	45.6	45.0	41.5	24.0

Columbia is now grown commercially in Missouri. For further information on this new oat, see Stadler and Kirkpatrick.[4]

[4]STADLER, L. J., and KIRKPATRICK, R. T. Columbia oats, a new variety for Missouri. Mo. Agr. Exp. Sta. Bul. 296. 1931.

TABLE 3.—*Annual and average acre yields of Franklin and three standard oat varieties grown in plats and nursery rows at Columbus, Ohio, in the years indicated.*

Variety	Yield in bushels per acre											
	1924	1925	1926	1927	1928	1929	1930	1931	Averages			
									1927–31	1928–31	1924–27 and 1929–30	1926–27 and 1929–30
Triplicated 1/100 Acre Plats												
Franklin (new)	—	—	—	61.0	46.5	50.8	49.6	58.8	53.3	51.4	—	—
Fulghum (standard)	—	—	—	56.2	37.5	48.7	45.0	52.6	48.0	46.0	—	—
Miami	—	—	—	57.1	55.9	43.9	43.2	35.8	47.2	44.7	—	—
Gopher	—	—	—	—	42.5	45.8	50.4	50.8	—	47.4	—	—
Replicated Rod Rows												
Franklin (new)	86.0	62.6	77.6	76.8	—*	54.3	38.9	—	—	—	66.0	62.1
Fulghum (standard)	84.6	56.3	63.0	72.6	—*	55.3	32.6	—	—	—	60.7	55.9
Miami	—	—	72.2	54.0	—*	49.4	45.0	—	—	—	—	55.2

*Crop destroyed by fire in 1928.

FRANKLIN, REG. NO. 79

The following paragraphs on the history, description, superior qualities, and performance of Franklin (C. I. No. 2892) were submitted with the application for registration by Dr. H. L. Borst:

History.—Franklin originated as a single plant selection from Fulghum (C. I. No. 708) made in 1922 by H. L. Borst, of the Department of Farm Crops, Ohio State University. Subsequent testing has been done by him at Columbus (the Ohio State University and the Ohio Agricultural Experiment Station cooperating), and by G. H. Stringfield, at the Ohio Agricultural Experiment Station at Wooster.

TABLE 4.—*Annual and average acre yields of Franklin and three standard oat varieties grown in plats and nursery rows at Wooster in the years indicated.*

Variety	Yield in bushels per acre								
							Averages		
	1926	1927	1928	1929	1930	1931	1929–31	1926–29	1926–31
	Quadruplicated 1/40 Acre Plats								
Franklin (new)	—	—	—	44.6	58.3	76.2	59.7	—	—
Fulghum (standard)	—	—	—	42.5	53.9	77.5	58.0	—	—
Miami	—	—	—	49.2	55.3	56.6	53.7	—	—
Gopher	—	—	—	49.6	62.2	57.8	56.5	—	—
	Triplicated 1/800 Acre Plats—Poor Land Test								
Franklin (new)	44.1	64.7	39.8	25.6	—	—	—	43.6	—
Fulghum (standard)	51.5	57.0	38.4	18.5	—	—	—	41.4	—
Miami	45.6	56.1	39.0	22.9	—	—	—	40.9	—
Gopher	42.9	64.7	45.4	24.8	—	—	—	44.5	—
	Triplicated 1/800 Acre Plats—Rich Land Test								
Franklin (new)	97.1	98.4	76.3	44.1	33.6	84.0	—	—	72.3
Fulghum (standard)	79.8	84.2	77.6	33.2	32.6	53.8	—	—	60.2
Miami	85.5	91.0	56.0	44.4	34.2	49.4	—	—	60.1
Gopher	71.3	96.6	79.1	42.2	33.1	51.6	—	—	62.3

Description.—During its test period at Columbus, Franklin has matured from two days earlier to four days later than Fulghum, and has ranged from four to eleven inches taller. It has a spreading panicle with a yellowish-white empty glume. The kernel is similar in color to that of Fulghum, perhaps slightly lighter in seasons of good weather. The straw has unusual stiffness in addition to its height. In appearance the selection is very uniform, being nearly free from the aberrant forms characteristic in Fulghum, although an occasional black kernel is produced.

Superior qualities.—Its superior qualities are its increased yield over Fulghum, which has been previously the outstanding oat as regards yield for southern Ohio, its greater stiffness and length of straw, and its uniformity and freedom from the aberrant forms occurring in Fulghum.

Performance record.—Franklin has been tested at Columbus, at Wooster, and on the various County Agricultural Experiment Farms. Records from Columbus and Wooster are given in the tables. Since the midseason varieties in general are better adapted to conditions at Wooster, the tests at Columbus are the more important indication of the performance of the variety.

The annual and average acre yields of Franklin and three standard varieties of oats grown in both plat and nursery experiments at Columbus and Wooster, are shown in Tables 3 and 4, respectively.

Franklin was grown commercially on farms in Ohio in 1931.

FELLOWS ELECT

WILLIAM WESLEY BURR

WILLIAM WESLEY BURR, University of Nebraska, Lincoln, Nebraska. Born at Goodland, Indiana, March 26, 1880. B.S., University of Nebraska, 1906. Assistant in crops and soils in charge of cooperative experimental work with the Office of Dry Land Agriculture, U. S. Dept. of Agriculture and the Nebraska Agricultural Experiment Station, 1906–1913; agriculturist, U. S. Dept. of Agriculture 1913–16; professor of agronomy and head of the department of agronomy and vice-director of the Agricultural Experiment Station, Nebraska University, 1916–1928; dean of agriculture and director of the Agricultural Experiment Station, University of Nebraska, 1928—. Member of A. A. A. S., American Society of Agronomy. Special interests include soil moisture, crop production and principles of cultivation, tillage methods and dry land agriculture.

In addition to serving the Society as its President during the past year, Dean Burr has served on the executive and various other committees, has participated frequently in the program of the annual meetings, and has made important contributions to agronomic knowledge.

MAX ADAMS McCALL

MAX ADAMS McCALL, United States Department of Agriculture, Washington, D. C. Born at Jamestown, Kansas, October 20, 1888. B.S., Oregon State College, 1910; M.S., Washington State College, 1922. Instructor in high school, Washington, 1910–11; instructor in agronomy, Oregon State College, 1911–12; instructor in high school, Oregon, 1912–14; county agricultural agent, Oregon, 1914; dry land specialist and superintendent, Adams Branch Experiment Station, Washington Experiment Station, 1914–24; agronomist in charge cereal crops, Office of Cereal Crops and Diseases, United States Department of Agriculture, 1924–30; principal agronomist in charge, Division of Cereal Crops and Diseases, United States Department of Agriculture, 1930—. Member A. A. A. S., American Society of Agronomy, and Genetic Association. Special interests, crop physiology, crop improvement, dry farming, and the development of better cooperative relationships between state and federal agencies interested in crops research.

In addition to serving on many standing and special committees of the Society, Mr. McCall has made valuable contributions to the programs of the Society and to crops research.

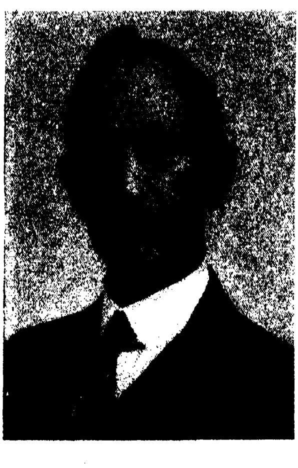
CHARLES FREDERICK SHAW

CHARLES FREDERICK SHAW, University of California, Berkeley, California. Born at West Henrietta, New York, May 2, 1881. B.S.A., Cornell University, 1906. Assistant in soils, Cornell University, 1905–06; assistant Bureau of Soils, U. S. Dept. of Agriculture, 1906–07; instructor in agronomy, Pennsylvania State College, 1907–09; assisttant professor in agronomy, Pennsylvania State College, 1909–13; professor of soil technology, University of California, 1913—; consulting engineer, United States Reclamation Service, 1919–26; irrigation commission, Republic of Mexico, 1926–27. Member A.A.A.S., American Society of Agronomy, American Geographical Society, and American Soil Survey Association. Special interests, soil technology, soil survey, alkali soils, land settlement, and crop adaptation.

Professor Shaw is a charter member of the Society, has served on many committees, and taken an active part on the programs for many years. He has made many valuable contributions to the science of soils.

FRANK DUANE GARDNER

FRANK DUANE GARDNER, Pennsylvania State College, State College, Pennsylvania. Born at Gilman, Illinois, November 19, 1864. B.S., University of Illinois, 1891. Assistant Agriculturist, Illinois Agricultural Experiment Station, 1891–1895; soils expert, Bureau of Soils, U. S. Dept. of Agriculture, 1895–1901; director Porto Rico Experiment Station, 1901–1904; scientist in charge of soil management, Bureau of Soils, U. S. Dept. of Agriculture, 1904–1908; head, department of agronomy, Pennsylvania State College, 1908—. Member of A.A.A.S., American Society of Agronomy. Special interests, soil fertility, crop improvement, and farm management. Author of *Farm Crops and Their Cultivation and Management.*



Professor Gardner is a charter member of the Society, has served on many committees, and through his council, teaching, and research, has given much for the advancement of agronomy.

WILLIAM HENRY STEVENSON

WILLIAM HENRY STEVENSON, Iowa State College, Ames, Iowa. Born at Freeport, Illinois, September 4, 1872. A.B., Illinois College, 1893; B.S.A., Iowa State College, 1905. D.Sc., Illinois College, 1923. Professor of soils, Iowa State College, 1902–10; vice-director of Iowa Agricultural Experiment Station, 1912—; head, department of agronomy, 1910–31. Iowa state drainage and conservation commission, 1908–10. Author of *Soil Physics and Laboratory Guide*. Member A.A.A.S., American Society of Agronomy, Iowa Academy of Science, and American Soil Survey Association. Special interests, soil physics, soil fertility, soil management, and soil survey.

Dr. Stevenson is a charter member of the Society. He has served diligently on many committees and programs since the Society was organized. His contributions to the field of soil science have been numerous and valuable.

AGRONOMIC AFFAIRS

MINUTES OF THE TWENTY-FOURTH ANNUAL MEETING OF THE SOCIETY

The meeting was called to order at 9:30 a.m. on Thursday, November 19, at the Stevens Hotel, Chicago, Ill. About 300 members and visitors were in attendance at the various sessions. Over 250 registered and received copies of the printed abstracts.

The following special committees were appointed: *Nominating*—L. E. Call, S. B. Haskell, and R. J. Garber; *Auditing*—Geo. Roberts and Richard Bradfield.

COMMITTEE REPORTS

TERMINOLOGY

Dr. C. A. Shull presented the report of the Committee on Terminology, which upon motion was accepted, as follows:

A year ago there was presented to the Society, and later referred to the Committee on Terminology, a request to recommend the adoption of the terms phosphoric acid and potash, in place of the terms phosphorus and potassium, in statements dealing with soils and fertilizers. In support of this request there were submitted records of action taken by the Association of Official Agricultural Chemists and of resolutions passed by the National Fertilizer Association. The Committee has considered the matter and submits its report, as follows:

The trend, both in science and in commercial fields, seems to be in the direction of increasing precision and accuracy in the designation of entities. The Committee feels that such trend is desirable and should be encouraged.

There is a discernible tendency toward the use of more specific terms in the fertilizer industry. Until recently it was customary to express nitrogen content as ammonia, whereas the universal present practice is to use the specific and accurate term nitrogen. The two present cases seem to belong in the same category.

With reference to the respective actions of the two official organizations noted above, it seems that the Association of Official Agricultural Chemists was then engaged in standardizing and making uniform their laboratory practice, rather than in considering the most desirable terminology, and that the National Fertilizer Association was merely determining the order of precedence of the three elements in formulas and was not considering the merits of the terms themselves. Both bodies previously had adopted the comparable term nitrogen, the element, in place of ammonia, the compound, when that question had come up for decision.

To your Committee it seems preferable to express phosphorus and potassium content as phosphorus and potassium, respectively, when the elements themselves are meant, or primarily involved, just as the term nitrogen is employed when that element is meant. Conversely the terms phosphoric acid and potash would be used when, and only when, it was desired to designate those specific compounds. Such usage would seem to be both precise and accurate and in line with recent tendencies.

In view of the apparent trends in usage, and the satisfactory progress that is being made, the Committee recommends that the Society take no further action at this time.

Respectfully submitted,

HARRY O. BUCKMAN — CHARLES A. SHULL
CHARLES F. SHAW — CARLETON R. BALL, *Chairman.*

STANDARDIZATION OF FIELD EXPERIMENTS

Dr. T. A. Kiesselbach, Chairman, presented the report of the Committee on Standardization of Field Experiments, which was accepted as follows:

Eight years have elapsed since the adoption by the Society of its present standards for field experiments. Those standards were introduced by the committee with the statement that they should stimulate further study with the understanding that the standards and rules then adopted are open to revision as better methods are divised.

In keeping with the spirit of that recommendation and in the light of more recent contributions to our knowledge concerning the conduct and interpretation of agronomic investigations, it is recommended that a committee be appointed with authority to undertake a revision of the original and supplementary standards which have been adopted. It is further suggested that these revised standards together with a complete bibliography be published in the JOURNAL upon adoption, and that reprints be made available for reference purposes.

A list of 35 titles is appended to this report as an addition to the bibliography. The committee looks with great favor upon the continued investigation and publication by agronomists concerning the conduct of field experiments.

ADDITIONS TO BIBLIOGRAPHY CONCERNING STANDARDIZATION OF FIELD EXPERIMENTS

Thirty-six titles are appended for inclusion in the bibliography, as follows:

ALLAN, F. E., and WISHART, J. A method of estimating the yield of a missing plot in field experimental work. Jour. Agr. Sci. 20:399–406. 1930.

BEHRENS, W. V. Zum Fehlerausgleich bei Feldversuchen. Landw. Jahrb. 70: 533–548. 1929.

BORDEN, R. J. Studies in experimental technique—shape, size, and replication. Hawaiian Planters' Rec. 35:295–304. 1931.

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R. J. GARBER	H. M. STEECE
C. A. MOOERS	J. W. WHITE
L. F. STADLER	T. A. KIESSELBACH, *Chairman.*

VARIETAL STANDARDIZATION

Prof. S. C. Salmon presented the report of the Committee on Varietal Standardization and Registration, which, upon motion, was adopted, as follows:

During the year three varieties of wheat and two varieties of oats have been registered. These varieties, with their registration numbers, are as follows:

	Variety	Registration No.
Wheat:	Gasta	268
	Cheyenne	269
	Komar	270
Oats:	Columbia	78
	Franklin	79

A detailed history of the origin of these varieties and of the data on which registration is based, are presented elsewhere in this number of the JOURNAL (pages 1010 to 1017).

A proposal has been made that the Society provide for registering improved varieties of canning peas. While grown on a field scale, this crop ordinarily is considered horticultural, and problems connected therewith usually are handled by horticultural agencies. The same also applies to sweet corn, registration applications for inbred lines of which also have been received. As registration by this Society is now organized, increasing the number of crops to be registered beyond strictly accepted field crops easily might make the work of registration an undue burden beyond what reasonably can be expected from voluntary service by the Varietal Standardization Committee. The matter coming up for consideration only shortly before this annual meeting, it has not been possible to submit it for expression of opinion to all members of the Committee. Several members of the Committee who have been consulted, however, are not in favor of registering either of these crops. The chairman believes that the matter should be decided by vote of the Society or by action of the Executive Committee and so recommends.

Plans for the registration of sorghum varieties are under consideration, but have not yet reached the point where they are ready for submission to the Society.

During the past three years, the Committee has been considering plans for registering varieties of cotton. Circumstances concerned with the crop itself and with agencies having to do with the improvement and distribution of many improved cotton varieties, make the registration of cotton more difficult than that of other crops, especially in safeguarding its integrity. In the first place, at the present time a large part of the best cotton breeding work is done by commercial agencies. In most instances, the men doing this work are high-grade individuals of undisputed integrity. It so happens, however, that in a number of instances these men, being leaders in their particular states, occupy rather important places on the governing boards of their state institutions. As a result, the agronomists of these particular states are placed in a difficult and embarrassing situation in that no matter how honest or careful they may be, data they might obtain concerned with the particular productions of such commercial interests might be questioned by their colleagues. Those in a position to judge feel, therefore, that it is necessary to provide for additional testing in such cases, if deemed necessary, by the registering agency. Cotton breeders also have a very strongly developed belief that because of such influences it is not proper to place the registration of cotton varieties too exclusively in the hands of one man. While they recognize that the registration of any variety is determined only upon the vote of the whole Committee of the Society, they feel that members of the Committee other than the individual versed in cotton must rely pretty largely on the opinions of this one man for their decisions.

Most of the cotton agronomists believe that the old subcommittee plan is better than the present general committee plan, so far as cotton is concerned. Since, however, the majority of the present Varietal Standardization Committee favor continuation of the present general committee plan, we are proposing, as an alternative to meet this objection, a cooperative undertaking between the American Society of Agronomy and the Agronomic Section of the Association of Southern Agricultural Workers, whereby a committee of that organization will be an integral part of the machinery for registering cotton varieties. It has been proposed at various times that the Agronomic Section of the Association of Southern Agricultural Workers become a section of the American Society of Agronomy. If this arrangement can be effected, it will solve the problem. If not, it seems to

the Committee that a successful cooperative understanding between the two Societies should be possible.

The Committee as a whole has not had an opportunity to pass on the final draft of the cotton registration plan. Its provisions have been submitted to them and have been approved as separate items, but the final draft of the plan was not submitted to all of them for action before this meeting. The plan as submitted, however, is in substantial agreement with the expressed wishes of the different Committee members as a whole. The plan submitted for action by the Society follows:

Registration of Cotton Varieties

The following regulations for the registration of cotton varieties, drafted by H. B. Brown, a member of the Varietal Standardization Committee, in consultation with interested cotton breeders, are proposed:

Object of Registration

The registration of cotton varieties should tend to stabilize varieties, should lessen the tendency of breeders and seedsmen to give variety names to strains that do not deserve varietal rank, and should improve cotton as an agricultural crop. To accomplish desired results registration must be generally used and the system must be simple and workable.

Eligibility

To be eligible to registry as a variety, a strain must be relatively uniform in plant characters, especially those of economic importance, and have well defined characters, either morphological or physiological, which distinguish it from other varieties. It must have been tested in comparison with standard varieties in well-replicated experiments at a Federal or State Experiment Station during a period of three or more years, and must have shown superiority over standard varieties in respect to yield or other important characters.

All data available will be considered in determining the eligibility of a proposed variety, and in case the data presented are not conclusive and convincing, the Committee may request that the strain be tested further.

Varieties that have been named and distributed prior to 1930 shall not be subject to registration as improved varieties, but as soon as descriptions of commercial varieties now in use are published in the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY, or elsewhere, application may be made for their registration as standard varieties.

Application for Registration

Persons desiring to have a new cotton variety registered shall make application to the cotton representative of the Varietal Standardization Committee of the American Society of Agronomy.

Applicants will be required to present six typical open bolls of the proposed variety and a mount consisting of 50 seeds with lint attached and combed so as to show length and uniformity of lint. These seeds are to be from 50 different plants selected at random in a field. The applicant will also be required to supply a limited amount of seed for further testing in case it is deemed necessary to obtain additional data.

Applicants will, in addition, be asked to supply the information requested on the accompanying blank form:

Application for the Registration of a Cotton Variety

Varietal name
Origin of the strain
  If a selection
    Vareity from which first selected
    Year selected
    Where selection was made
    Subsequent handling of the selection as to further selection, roguing, and increase
  If a hybrid
    Name of varieties crossed
      Pistillate parent
      Staminate parent
      Year cross was made
      Where strain was developed
      Subsequent handling of the strain as to number of years inbred and selected in breeding plats, etc.
Number of years tested by breeder
  Size of plats
  Number of replications
  Location of tests
Number of years tested by Experiment Stations
  Size of plats
  Number of replications
  Location of tests
Special merit of proposed new variety
Name and address of breeder
Name and address of applicant
Brief description of proposed new variety
  (This description should detail characters such as are to be observed when plants are grown under average conditions, and should cover size of plants, branching habits, foliage, boll size, length of lint, size and color of seed, lint percentage, disease resistance, earliness, productiveness, etc.)

Experimental data from tests in which the proposed new variety was grown in comparison with standard varieties.

Varieties	Lint per acre (pounds)	Lint, %	Length of lint (inches)	Bolls of seed cotton per pound	Wilt infected plants, %	By whom tested	Location of test	Year
								19
								19
								19

(This form may be extended to include all data available.)

Registration

Consideration of the application, registration, and the publication of the same shall proceed as outlined for the registration of varieties of other crops by the

Varietal Standardization Committee of the American Society of Agronomy, except that the cotton representative shall consult with a registration committee appointed by the Agronomic Section of the Association of Southern Agricultural Workers, under a cooperative agreement between the American Society of Agronomy and the Agronomic Section of the Association of Southern Workers, and recommendations shall be based on a joint report including the concensus of opinion of this Committee.

The following registration certificate form is suggested:

Improved Cotton Varieties

The strain of cotton designated as..
and developed by..
is accepted as a variety of merit by the committee on the registration of field crop varieties this.................. day of.. 19........, and given the Registration Number...............................

Cotton Representative, Committee,
American Society of Agronomy

Chairman, Var. Stand. Com. Amer.
Soc. of Agronomy
In charge of Register for U. S. Bur. Plant Ind.

Respectfully submitted,

E. F. Gaines, H. K. Hayes, H. B. Brown, D. F. Jones, J. H. Parker, T. R. Stanton, J. A. Clark, F. D. Richey, M. A. McCall, *Chairman.*

FERTILIZER DISTRIBUTING MACHINERY

Prof. Emil Truog, Chairman, presented the report of the Joint Committee on Fertilizer Distributing Machinery, which, upon motion, was adopted, as follows:

The Committee on Fertilizer Distributing Machinery, working in cooperation with the Joint Committee representing the National Fertilizer Association, the American Society of Agricultural Engineers, the National Association of Farm Equipment Manufacturers, and the American Society of Agronomy, reports as follows:

1. The hand fertilizer placement test with corn has been continued the past season in cooperation with 24 State Agricultural Experiment Stations. The results corroborate those of previous years. The Committee believes that in hill fertilization of corn the fertilizer should be placed in lateral bands separated horizontally at least 1¼ inches from the seed and located vertically from one inch above to one inch below the seed. The Committee feels that this recommendation is sufficiently well established to warrant manufacturers to use it as a basis for the design of their machines.

2. Performance tests of fertilizer attachments on corn planters have been continued by a sub-committee and have established the superiority of those improved devices which place the fertilizer in lateral bands approximately as in the foregoing recommendation. It is recommended that this work be continued and extended to include a wider range of soil and climatic conditions.

3. Largely through the efforts of the U. S. Bureau of Chemistry and Soils and the U. S. Bureau of Agricultural Engineering, tests on machine placement of fertilizer for cotton have been carried on in cooperation with 8 State Agricultural

Experiment Stations. Publication of the results of these tests will follow shortly through the appropriate channels. Similar work has been carried on with potatoes in three states, with beans in two states, and with sweet corn in one state. It is hoped that this work will be continued.

4. It is recommended that the Society again appoint a committee to continue the work.

J. R. Fain
A. H. Meyer
C. O. Rost
R. M. Salter
J. J. Skinner
W. L. Slate
Emil Truog, *Chairman.*

FERTILIZERS

Dr. F. E. Bear presented the report of the Committee on Fertilizers, which, upon motion, was accepted, as follows:

This committee has continued its work on the two projects presented in its last annual report. Progress has been made as follows:

1. Dr. B. L. Hartwell, formerly agronomist and director of the Rhode Island Station, has devoted what time he could spare from his regular duties to the study of the literature bearing on the question of the effect of fertilizers on the quality of crops. The task has proved so enormous that it is not yet completed. Several hundred references have been compiled from American and European sources. These have been integrated and studied. The first draft of the report is nearly completed. It is the purpose of this committee to bring the first draft of the report to the attention of this Society in some appropriate manner before final publication. This work is supported financially by a grant from National Fertilizer Association which thru its executive secretary Chas. J. Brand is cooperating with this committee in this project.

2. In its last report this committee called attention of the Society to the unsatisfactory state of our knowledge concerning the proper ratio of nutrients required by and to be recommended for our common crop plants. In its broader aspects this problem is both physiological and agronomical. First, it is desirable to know the physiological relations of the plant and the nutrients commonly supplied in fertilizers. Second, in its final analysis the problem is agronomical, extremely complicated by superimposing the physiological relationship on a heterogenous and variable soil medium. It would appear logical first to solve the physiological phases of the problem, and later the agronomical phases, but practically we cannot wait for this procedure. No doubt we shall have to proceed largely in an empirical way for the present.

However, we wish to encourage plant physiologists to work on the problem of nutrient ratios for crop plants. Much work needs to be done in this field.

One member of this committee has made a study of the American literature bearing on the question of the proper fertilizer ratio for the hay crop. This study has revealed a very inadequate supply of data for drawing definite conclusions as to the proper nutrient ratio of N, P_2O_5, and K_2O for the hay crop. Because of lack of replications of treatments and the short duration of many of the experiments, data from most of the earlier experiments show only trends. Generally speaking, a ratio of 1:1:1 represented by a mixed fertilizer carrying about 50 pounds per acre each of N, P_2O_5, and K_2O has produced optimum and in some cases maximum yields. Clearly nitrogen has been the dominant element in producing hay composed largely of grasses, and there is considerable evidence that the proportion of

nitrogen should be higher than that in the 1:1:1 ratio. Most of the experimental data involve rather large increments of nutrients. A statistical study of the results of a Pennsylvania experiment involving increments of 4.1 lbs. N showed that increments of at least 12.3 pounds per acre of N (15 lbs. NH_3) were necessary to produce significant changes. In view of these and other data this Committee states that there is not now sufficient evidence to recommend grass topdressing mixtures closer than 10 pounds N, 40 pounds P_2O_5, and 20 pounds K_2O per acre. For example, considering a recommendation of 500 pounds of a 10–10–10 grade, the recommendation should be 10 ± 1—10 ± 4—10 ± 2. These figures frankly are tentative and should be changed if and when sufficient evidence warrants a change. More and more carefully planned experiments are needed with reference to this problem. A standardized plan for such experiments would facilitate interpretation and comparison of results.

Studies of the literature on the nutrient requirements of the corn and cotton crops similar to that which has been made for the hay crop are under way.

We recommend that this committee be continued with instructions to continue work on the projects now under way.

H. J. Harper F. E. Bear
M. F. Miller A. B. Beaumont, *Chairman.*

EUROPEAN CORN BORER INVESTIGATIONS

Dean L. E. Call, Chairman, presented the report of the Joint Committee on Corn Borer Investigations which, upon motion, was accepted and the Executive Committee was urged to consider the advisability of sending copies to the Ways and Means Committees of the Senate and House. The report is as follows:

The natural spread and increase of the European corn borer, which was retarded by the abnormal season of 1930, was resumed in 1931. The intensity of infestation in 1931 was about two and a half times that of 1930 and more than twice that of 1929. Although the past season cannot be regarded as having been exceptionally favorable for the corn borer, some of the serious infestations recognized as possible in the 1930 report of this committee actually occurred. As a result, there is a much larger number of larvae at present than in the fall of 1930, with a consequently greater danger for 1932. The increase in borer population was particularly heavy (1) in northwestern Ohio, south of the former center of infestation along Lake Erie, and (2) in the important sweet corn area along the southern and eastern shores of Lake Ontario in New York.

The present infested area includes all of the corn-growing areas in Canada, excepting the western provinces; also 220,000 square miles in the United States, including the southern two-thirds of New England, northern part of New Jersey, all of New York, three-fourths of Pennsylvania, the panhandle of West Virginia, practically all of Ohio, the northeastern half of Indiana and nearly all of the agricultural portion of Michigan. In the area east of the Connecticut River in Connecticut, Massachusetts and states north, in that territory in Connecticut west of the river adjacent to Long Island Sound, and in restricted localities in New Jersey, the two-brooded form occurs, while in all other infested sections of the United States and all infested areas in Canada, excepting Nova Scotia and New Brunswick, only the one-brooded form occurs. Small isolated infestations occurred in eastern Wisconsin, Kentucky, and extreme southern Indiana.

The increase in spread and infestation in 1931 further demonstrates that seasons of increase and decrease in borer abundance will occur as with other crop

pests. Temporary checks to the corn borer in individual seasons, such as that in 1930, must not be interpreted as minimizing the seriousness of the insect as a destructive agency.

The large increase in borer population in 1931 emphasizes that the European corn borer is one of the most potentially destructive crop pests ever introduced into America. This fact calls for the continued cooperation of the farmer, the scientist, the educator, and all State and Federal administrative officials.

The joint committee of entomologists, agronomists, agricultural engineers, agricultural economists, and animal husbandmen, commends the efforts of all farmers practicing recommended control measures and of those engaged in the research, regulatory, and educational activities.

The committee recognizes the necessity for the continuation of the research, educational, and quarantine programs of the State and Federal Governments and earnestly recommends the appropriation of the funds needed to maintain and, if necessary, to expand them as suggested later in this report. The committee recommends this support only after due consideration of the absolute necessity of holding current governmental expenditures to a minimum.

After careful investigation of the regulatory, research, and educational activities, the committee suggests and recommends:

1. Since the enforcement of quarantine regulations in the United States has undoubtedly been instrumental in preventing long distance spread of the insect in the past, that this activity of the Federal Governments of the United States and Canada, as well as the State and Provincial governments, be supported and encouraged by all agencies and individuals interested in the welfare of American agriculture. These activities should include: (a) thorough scouting, (b) careful clean-up of isolated infested areas, and (c) maintenance of quarantines.

2. That the extension agencies of the Federal governments of the United States and Canada and of the State and Provincial agricultural colleges, strengthen and coordinate their programs of education relating to the corn borer, extending these to conform with the spread and abundance of the insect and with the increased knowledge gained through research.

3. The entomological investigations now in progress should be continued. The following studies on which material progress already has been made, should be especially stressed: (a) the expedition of parasite introductions and the development of artificial media for mass production of parasites, (b) the development of effective insecticides and their efficient application, (c) evaluation of the effect of environmental factors on the insect's activity.

4. While the development of immune varieties seems unlikely at this time, experiments point clearly to the probable development of high yielding resistant and tolerant varieties of corn which should be an important factor in control. To promote the development of such varieties, the corn breeding programs of the State and Federal governments should be continued and strengthened.

5. Inasmuch as control of the borer, as yet, depends largely upon mechanical means in the hands of growers, it is recommended that research and development work along mechanical lines by the agricultural engineers be continued and be strongly supported by the Federal Government and by the States, with a sincere effort being made to coordinate such activities through the Bureau of Agricultural Engineering. In such work it is recommended that attention should be directed first toward machine types now common on farms, in view of the fact that agriculture cannot easily avail itself of new types of equipment primarily for control until it has used to the best possible advantage the equipment now on farms.

Attention is drawn to the fact that considerable development work has been accomplished and now awaits adoption by the various extension forces and by the manufacturers of farm equipment. It is recommended that the extension forces bear in mind that the better use of equipment now on farms is to be fostered.

The manufacturers are to be commended for their interest and loyal support in corn borer work to date, and, in spite of the readjustment period, it is hoped that they will continue rapidly to convert development accomplishments into the commercial channels, so that the growers—who must carry the burden of control—will not be handicapped by the latest, practical, mechanical devices not being available to the public.

6. Since the corn borer control practices developed and proposed may change the organization and income of the farm it is important that the relation of these practices to the entire farm business be determined and recommendations made for specific conditions. Proposals including changes in cropping systems, complete utilization of corn, substitute crops, changes in corn acreages, and labor and equipment costs should be worked out in line with the objective of maximum returns from farming.

7. Continued and further studies should be made on the influence of different borer populations upon (a) feeding value of corn and the corn plant in different forms, (b) upon the yield of feed nutrients per acre, (c) comparative feeding value due to different methods of harvesting and preparing crop, (d) use and feeding value of substitute crops, and (e) the influence of the corn borer and resultant control measures upon the cost of production and the quality of livestock products.

Respectfully submitted,

American Association of Economic Entomologists:

G. A. DEAN D. J. CAFFREY
L. CAESAR T. J. HEADLEE
J. J. DAVIS

American Society of Agronomy:

L. E. CALL J. F. COX
W. L. BURLISON R. M. SALTER
F. D. RICHEY

American Society of Agricultural Engineers:

C. O. REED A. L. YOUNG
W. C. HARRINGTON R. B. GRAY
R. D. BARTON

American Farm Economic Association:

E. D. HILL J. COKE
C. R. ARNOLD LYNN ROBERTSON
C. L. HOLMES R. R. HUDELSON

American Society of Animal Production:

E. W. SHEETS PAUL GERLAUGH
F. G. KING G. A. BROWN
F. B. MORRISON

SPECIAL JOINT COMMITTEE WITH THE INTERNATIONAL CROP IMPROVEMENT ASSOCIATION

Prof. G. H. Cutler, Chairman, presented the report of the Joint Committee with the International Crop Improvement Association which, upon motion, was adopted and the committee discontinued. The report is as follows:

Terminology of Seed of Improved Varieties

During the past year the Committee on Terminology of Seed of Improved Varieties has re-canvassed the opinion of plant breeders and agronomists regarding the need of further terms for seed of improved varieties. As a result it finds that the general feeling seems to be that the three terms named and defined by this committee in JOUR. AMER. SOC. AGRON. Vol. 21, No. 12, p. 1202, meet the present situation quite adequately. In this view the joint Committee representing the International Crop Improvement Association concurs.

In as much, therefore, as there does not appear to be a need for further terms at the present time, the committee recommends that this brief report be accepted and the work of the committee be discontinued.

Respectfully submitted,

R. A. MOORE	F. P. BUSSELL
CLYDE MCKEE	P. C. MANGELSDORF
L. W. FORMAN	G. H. CUTLER, *Chairman.*

COMMITTEE ON REORGANIZATION OF THE SOCIETY

Prof. M. F. Miller, Chairman, presented the report of the Special Committee on reorganization of the Society, which, upon motion, was adopted by sections as follows:

The committee appointed to consider a plan of reorganization of the American Society of Agronomy has considered various proposals. It has had four meetings during the year, one at Washington at the close of last year's meeting of the Society and one at Chicago this year where practically the entire committee was present. One held at Cleveland at the time of the A.A.A.S. meeting and another at the Pennsylvania State College last June were attended by only a part of the committee. In addition, considerable correspondence has been carried on throughout the year. It was early found that the committee could not agree on any very radical changes in the organization.

The essentials of the plan which was finally worked out were mailed to 57 departments of Agronomy, Soils, and Crops throughout the country in order to get group action from each of these on the proposals suggested. Forty-four departments responded and the majority votes on the various items of the suggested plan were used to guide the committee in its final report. The plan proposed includes five items for consideration which are as follows: (1) the name of the organization; (2) the sectionizing of the Society; (3) officers; (4) membership; and (5) journals.

The committee wishes therefore to submit the following report under these five subdivisions.

1. Name of the Society:

Because of the fact that the name "American Society of Agronomy" is considered to be etymologically incorrect, two other names were suggested,—"The American Society of Agronomists" and "The Association of American Agronomists." The concensus of opinion of the various departments reporting was that the present name be retained. The committee concurs in this opinion. It wishes to recommend, therefore, that the original name, "The American Society of Agronomy" be retained.

2. Sectionizing the Society:

There has been a strong demand from various quarters for sectionizing the Society. It was early discovered, however, that the committee could not agree on more than two sections, a *Soils Section* and a *Crops Section*. This proposal was therefore submitted to the departments interested and of the thirty-four departments voting on this proposal twenty-eight were in favor of it and six were opposed. Several expressed no preference. The committee has agreed unanimously on this proposal and it wishes therefore to recommend that the Society be divided into two organic sections—a Soils Section and a Crops Section, and that each section be allowed to work out such subsections as it sees fit.

3. Officers of the Society:

(a) Officers of the General Society:

The committee was of the opinion that if the society were divided into two organic sections, each would necessarily have a chairman who might well serve as a member of the executive committee. In this case the plan of continuing four vice-presidents would seem to be inadvisable. It therefore wishes to recommend as follows regarding officers:

It is proposed that the officers of the Society shall consist of a president, a vice-president, a secretary-treasurer, and the editor of the JOURNAL, who shall be members of the Executive Committee. (The departmental vote on the matter of officers showed 35 to be in favor of this proposed plan while six were opposed to it.)

It is proposed that the vice-president shall be elected annually and that he shall automatically succeed to the presidency, thus giving him a year's direct contact with the affairs of the Society before assuming the office of president. The secretary-treasurer and the editor shall be appointed by the Executive Committee. It is believed that the limited amount of succession in office provided by the advancement of the vice-president to the presidency is desirable.

It is proposed that the vice-president shall be elected after nominations have been submitted by a nominating committee of which the president of the Society shall be chairman and which shall include two additional members from each of the sections, to be appointed by the sectional chairmen.

It is suggested that the vice-president be chosen alternately from the two sections. It is believed that the best interests of the Society will be served if the sectional chairmen are eliminated from consideration as nominees for the vice-presidency.

(b) Officers of the Sections:

It is proposed that each of the two sections shall provide a chairman who shall be chosen by the individual sections and who shall represent those sections on the Executive Committee of the Society. These chairmen shall be elected at the annual sectional business meetings. Any additional sectional officers shall be determined by the individual sections.

(c) Program Officers:

It is proposed that the annual meeting of the Society consist of one or two general sessions as well as sectional sessions in Soils and Crops. The president and vice-president of the Society shall be responsible for organizing the programs of the general sessions. The two sectional chairmen shall be responsible for organizing the programs of their respective sections. The president shall appoint a member of the Society from among those interested in agronomic extension to organize an extension program when desired.

4. Membership:

The committee is of the opinion that a change should be made in the status of associate members. It is also proposing certain modifications in the definition of the other classes of members. It therefore wishes to recommend the following regarding classes of members:

(a) The Society shall be made up of four classes of members (1) Honorary; (2) Fellows; (3) Active; (4) Associate.

(b) The status of these four classes shall be defined as follows:

(1) Honorary members may be chosen by the Society from among distinguished colleagues.

(2) Fellows may be chosen by the Executive Committee from the members whose professional records warrant recognition.

(3) Active members shall be those persons who are interested in the objects of the Society.

(4) Associate members shall be those who are interested in the objects of the Society but who do not wish to become active members. They may participate fully in all meetings and may offer papers for publication in the JOURNAL of the Society, but they shall not receive the JOURNAL nor have a vote in the general society excepting on matters pertaining to the subsections in which they are interested.

5. Journals:

In the event that the sectionizing of the Society were carried out the question of establishing two journals naturally arose. This was given much consideration. This of course is impractical with the present state of finances and there is a grave question as to its desirability. The vote of the departments was strongly in favor of maintaining a single journal, at least for the present, and to this the committee unanimously agrees. It wishes to recommend therefore that the existing journal, the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY, be retained. It is realized, however, that the journal situation is one of vital importance, and the committee wishes to recommend further that a committee be appointed to study the matter of society publications.

Respectfully submitted,

T. A. KIESSELBACH	S. A. WAKSMAN
R. J. GARBER	S. C. SALMON (for M. A. MCCALL)
C. W. WARBURTON (for O. S. FISHER)	RICHARD BRADFIELD
C. F. SHAW	C. R. BALL (not present)
C. F. MARBUT	J. D. LUCKETT, *ex-officio*
R. I. THROCKMORTON	P. E. BROWN, *ex-officio*
	M. F. MILLER, *Chairman*.

It was moved and carried that two special committees be appointed by the President to prepare the programs for the sections at the next annual meeting and formulate plans for the operation of the sections.

The Society then adjourned to attend the Land Utilization Conference and hear the address of Secretary Hyde.

At 2:00 p.m. the programs arranged were presented as outlined in the abstracts of papers on pages 1049 to 1077 of this number of the JOURNAL.

At 6:30 p.m. the annual dinner was held in the Stevens Hotel and Dean W. W. Burr delivered the address of the retiring president (pages 949 to 950).

The report of the Historian, Dr. T. L. Lynn, was read by the Secretary, as follows:

NOTES ON THE HISTORY OF THE SOCIETY

To determine the nature of his duties is perhaps the most difficult thing that the historian of a society of this kind has to do. Naturally the important proceedings of the organization are recorded in its minutes and its papers. These really constitute the history of the Society.

However, it is necessary that an historian shall offer some excuse for his incumbancy. History as a science appears to consist mainly in the interpretation of the actions of a people. A study of the trends and the significance of the doings of this Society might well constitute a theme for its Historian. Another phase might perhaps consist in recording the personal element in the life of the organization, which otherwise is likely to be lost. At best the contributions must be more or less fragmentary and sporadic rather than connected and finished productions. This also permits them to be brief which will probably be their greatest virtue during the incumbancy of the present Historian.

A number of those present will remember that the Society was organized at a meeting called by M. A. Carleton and 42 others and held in Chicago during the meeting of the American Association for Advancement of Science in December, 1907. There were a considerable number of people in attendance at this first meeting, but not as many as signed the call. Following the organization of the Society members were quickly recruited and by July 1, 1908, the number of members credited with dues for the first year was one hundred and one. It had previously been decided that these were to be considered charter members. This large number of charter members gave evidence that the time was ripe for the formation of the Society. No set back was experienced at any time in the history of the organization. By 1910 the membership had increased to 176. The roll published in 1926 contained 700 names; in 1931, 963.

In the 24 years during which the Society has been in existence nearly one-fifth of the charter members have been removed by death. One-half of the original members have withdrawn from the Society, in all cases apparently because they have left agronomic work. Many of these were young men, some being undergraduate or post graduate students at the time the Society was formed. Thirty-two of the charter members have withstood the temptations to leave an agronomic career and are still members of the Society. Most of these thirty-two are now connected with the same institutions in which they held positions in 1907.

The following charter members are now on the rolls of the Society:

C. R. Ball	J. G. Lipman	L. H. Smith
J. A. Bizzell	T. L. Lyon	W. H. Stevenson
H. L. Bolley	A. G. McCall	F. W. Taylor
B. E. Brown	M. F. Miller	R. W. Thatcher
Lyman Carrier	C. A. Mooers	J. D. Tinsley
F. D. Farrell	R. A. Moore	J. M. Westgate
E. O. Fippin	J. O. Morgan	H. J. Wheeler
F. D. Gardner	M. L. Mosher	A. R. Whitson
A. F. Gustafson	O. Schreiner	A. T. Wiancko
A. Keyser	H. L. Shantz	C. G. Williams
A. F. Kidder	C. F. Shaw	

Next year will be the 25th anniversary of the founding of the Society. It would be interesting to have photographs taken in or near 1907 of such of the charter members as have constituted the membership during the first quarter century of the Society's existence.

T. L. Lyon, *Historian.*

NOMINATING COMMITTEE

Dean L. E. Call, Chairman, presented the report of the Nominating Committee as follows: For President, Dr. P. E. Brown; for 4th Vice-President, Dr. M. A. McCall; for representatives on the Council of the A.A.A.S., Dr. A. B. Beaumont and Dr. S. C. Salmon. Upon motion, a unanimous ballott was cast for these officers and they were declared elected.

RESOLUTIONS

Dr. S. B. Haskell, Chairman, presented the report of the Committee on Resolutions as follows, which, upon motion, was adopted:

At the last annual meeting of the Society the committee on resolutions recommended to the Executive Committee that it appoint a standing committee on resolutions to serve throughout the year. It was further recommended that apart from routine matters that might come before this committee for action it should become one of its functions to note the passing of members of the Society and of others who have done outstanding work in agronomy. Also, appropriate action was to be taken by this proposed committee on developments of a political nature or otherwise that might affect the welfare of agronomists or agronomic research. The Executive Committee accepted this proposal and the President appointed the committee on resolutions as now constituted as a standing committee of the Society.

So far as we are aware there are no circumstances at present calling for action by this committee on conditions affecting agronomic work. It is our sad duty, however, to note the passing, since the last meeting of the Society, of six outstanding figures in the field of agronomy. These are Dr. Felix Löhnis, who died in Leipzig, Germany, on December 8, 1930; Dr. Martinus Willem Beijerinck, who died near Gorssel, Holland, on January 1, 1931; Dr. Louis Hermann Pammel, who died enroute from California to Ames, Iowa, on March 23, 1931; Dr. Whitman Howard Jordan, who died at Orono, Maine, on May 8, 1931; Dr. Russell Arthur Oakley, who died at Monrovia, California, on August 6, 1931; and Dr. Lucius Li coln Van Slyke, who died at Geneva, N. Y., on September 30, 1931.

Brief memorial statements relating to the life and work of each of these men have been prepared by those closely associated with them or well informed as to their contributions to agronomy. We recommend that these statements be made part of this report and that the whole be printed in the JOURNAL as part of the proceedings of this meeting.

Your committee recommends further:

THAT the American Society of Agronomy hereby express its appreciation of efforts being made during the progress of this meeting, by the present "Conference on Land Utilization," to arrive at a *National Policy for Agriculture.*

THAT we appreciate the sentiments of the Honorable Secretary of Agriculture, in his address of the morning.

FURTHER, THAT, we respectfully offer every aid within the scope of this organization and its membership, in arriving at a dependable body of fact which may serve as a basis for Soil Classification and Valuation.

It also recommends that, in case of acceptance, the incoming Executive Committee be requested to transmit this action to the Secretary of Agriculture, together with such supporting information as to possible service of the Society as may be justified by the circumstances.

In view of the fact that the 25th Annual Meeting of the Society is scheduled for November 1932; and that with the meeting of November, 1933, the Society completes the first quarter century of its existence, your committee recommends that the Executive Committee of the Society be requested to plan for fitting recognition of the occasion at one or the other of the above meetings.

The memorial statements follow:

Felix Löhnis

1874–1930

Dr. Felix Löhnis, world-renowned agricultural bacteriologist, director of the Institute of Agricultural Bacteriology and Soil Science at Leipzig, Germany, died in Leipzig on December 8, 1930.

Dr. Löhnis was a member of the Bureau of Plant Industry, United States Department of Agriculture, from 1914 until 1925, resigning the position of senior bacteriologist in charge of Soil Bacteriology Investigations in 1925 to return to Germany to become Professor of Agricultural Bacteriology at the University of Leipzig and Director of the Institute of Agricultural Bacteriology and Soil Science. Under his leadership 34 doctors' dissertations were completed by students from many countries throughout the world. Among the many brilliant studies reported either by Dr. Löhnis or his students that which will probably exert the greatest influence on future researches in bacteriology is his announcement in 1918 in the Memoirs of the National Academy of Science of definite cycles of growth and the wide range of morphological variation including a symplastic, or fusion, stage in the normal development of bacteria.

Dr. Löhnis was born in Dresden in 1874, and was educated at the Universities of Jena, Halle, and Leipzig. For eleven years prior to his coming to the United States he was head of the laboratory of agricultural bacteriology at the University of Leipzig. He was the author of many articles both in German and English announcing important discoveries, but was perhaps most widely known for his Handbuch der landwirtschaftlichen Bakteriologie. A second edition, which would bring together all the literature on agricultural bacteriology up to date, was nearing completion at the time of his death. Other books on agricultural bacteriology are widely known; for example, Einführung in die Bakteriologie, Vorlesungen über landwirtschaftliche Bakteriologie, Text Book of Agricultural Bacteriology (with Professor E. B. Fred), and Landwirtschaftlich-bakteriologisches Praktikum, the last being translated into English, French, Japanese, Polish, and Russian.

An indefatigable investigator and prodigious reader, he nevertheless found time to be an inspiring influence to investigators in many lines of agricultural research, as is attested by his former students and immediate associates. Dr. Löhnis' reviews of publications in the Centralblatt für Bakteriologie, of which he was editor, and elsewhere were usually brief, according praise to the discoveries he considered significant and well presented, but shrewdly critical and severe toward those that he considered carelessly performed or flamboyantly presented. Among his intimate friends, however, the severe critic was completely overshadowed by his versatility and genial good fellowship. An accomplished musician—a pianist of almost professional ability, a philosopher of wide vision and mature experience, and a humorist of most scintillating wit—evenings spent in his company will always be treasured memories.—K. F. Kellerman.

Martinus Willem Beijerinck

1851–1931

In a country home, close to Gorssel, in the Eastern part of Holland, died, on January 1, 1931, Professor M. W. Beijerinck, whose work in the field of Microbiology in general and of Soil Microbiology in particular is of the greatest theoretical and practical importance.

Beijerinck's first outstanding scientific contribution was of a botanical nature, on a subject bordering between botany and microbiology, namely, his work on the plant galls, which appeared in 1877. His interest in microbiology was aroused in 1885 when he was invited, at the recommendation of Hugo de Vries, by the Netherland Yeast and Alcohol Factory to undertake a series of studies of the growth of micro-organisms. This resulted in an investigation published in 1887 on the rôle of free oxygen in the life processes of the organisms bringing about fermentation. In this work he was a direct successor of Pasteur, who elucidated 25 years previously the principles of anaerobiosis as "life without oxygen."

It was, however, in 1888, when Beijerinck announced to the world the isolation of a bacterium concerned in the formation of nodules on the roots of leguminous plants, the now famous *Bacillus radicicola*. This was the first of a series of brilliant contributions to the subject of soil microbiology, which has helped in attracting universal attention to the rôle of micro-organisms in soil processes and plant growth.

In 1895, Beijerinck was appointed Professor of Bacteriology at the Polytechnical School in Delft. It was in this laboratory where the most outstanding work in microbiology by Beijerinck and his pupils and associates, which came to him in increasing numbers, was carried out. The investigation of the sulfate-reducing bacteria (*Spirillum desulfuricans*) appeared in 1896, of *Azotobacter* in 1901, of the sulfur-oxidizing bacteria (*Thiobacillus* group) in 1903, of the bacteria bringing about denitrification in 1903, all of which are of the greatest importance in soil science. In addition to these, Beijerinck's investigations dealt with the butyl-alcohol and butyric acid bacteria, the lactic acid and acetic acid bacteria, the microbes active in the retting of flax, the micro-organisms of kefir, as well as the nutrition of algae, amoebae, yeasts and fungi, embracing nearly every branch of microbiology. Plant pathology benefited considerably not only from his work on the root galls, but also from his study of the contagious nature of "gummosis" (1882), as well as of the mosaic in tobacco plants ("contagium vivum fluidum").

Beijerinck's name will always be connected in the history of microbiology with that of the pioneer, who opened up numerous fields of investigation. In this respect he is a direct descendant of his other great countryman, namely, Antonie van Leeuwenhoek. His work was progressing so rapidly, and numerous ideas and discoveries were made in such rapid succession, that he could never bring himself to write a book on this subject. Several attempts were made to write an all-embracing book, such as the tentative "Ecology of Microbes," but it was never written.

Beijerinck's investigations pointed the way to numerous applications of micro-organisms in natural processes. At an age when the microbes as pathogenic organisms were attracting universal attention, the work of Beijerinck emphasized the useful functions of the numerous microbes in agriculture and in industry. Beijerinck's contributions to soil science bridged the gap between the growth of plants and soil processes, as indicated by his work on the root galls and nodule bacteria. Towards the end of his life he returned to botany, as indicated by his

papers on regeneration of buds, position of leaves, etc. However, although botany and plant anatomy, microbial physiology, and microbial ecology will always be indebted to him for his great contributions to the respective sciences, it is soil microbiology that has benefited most from the work of this man of genius.

His numerous pupils, his still larger number of friends and visitors who have gained from his magnetic personality, and all those who were guided in their work by his ideas and discoveries will deplore deeply the loss that science suffers from the passing of this indefatigable investigator.—SELMAN A. WAKSMAN.

LOUIS HERMANN PAMMEL

1862–1931

Dr. L. H. Pammel, Professor Emeritus of Botany at the Iowa State College, died on March 23, 1931, enroute from California to Ames on his return from a three months' speaking trip throughout Southwestern United States and from a visit with a daughter in California. Dr. Pammel was born on April 19, 1862, in LaCrosse, Wisconsin. He graduated from the University of Wisconsin in 1885 and received the Master of Science Degree from the same institution in 1889. From 1886 to 1889, he worked with Dr. Trelease in the Shaw School of Botany, St. Louis, and also carried special work for the U. S. Department of Agriculture. In 1889, he came to the Iowa State College as Professor of Botany, which position he held until 1929 when he became Emeritus Professor of Botany. He also held the position of Botanist on the Agricultural Experiment Station Staff. He received the degree of Doctor of Philosophy from Washington University in 1898, and the honorary degree of Doctor of Science at the University of Wisconsin in 1925. He developed the Department of Botany at the Iowa State College to a staff of thirteen specialists offering 66 courses. He was the first chairman of the Iowa State Board of Conservation, serving from 1918 to 1927. He was largely responsible for the establishment of the State Board of Conservation, and under his regime, 38 state parks were laid out. He was the author of hundreds of scientific papers and monographs on Botanical subjects. His book on "Poisonous Plants" is recognized as the most comprehensive work ever completed on that subject. He was a member of numerous scientific societies, having been President General of Phi Kappa Phi, Vice-President of the American Association and Chairman of Section G (Botany), and prominent in many other organizations. He was President of the Iowa Academy of Science in 1893 and again in 1923. Besides his book on "Poisonous Plants", he published books on "Weeds", "Weed Flora of Iowa", "Grasses of Iowa", "Honey Plants of Iowa", and other subjects.

Dr. Pammel was married in 1888 and is survived by his wife and six children.—P. E. BROWN.

WHITMAN HOWARD JORDAN

1851–1931

My personal acquaintance with Dr. Whitman H. Jordan was limited to the annual conventions of the Association of American Agricultural Colleges and Experiment Stations, where I found him a clear thinker and a ready and forceful speaker, commanding the attention and respect of his audience. His membership for eighteen years in the Executive Committee of that Association is sufficient evidence of the reliance which his compeers placed upon the wisdom and stability of his character, and he has left an honorable record in his Directorship of the Maine and New York Experiment Stations, both as administrator and as scientist.—CHAS. E. THORNE.

Russell Arthur Oakley

1880–1931

In the death of Dr. R. A. Oakley, at Monrovia, California, on August 6, 1931, the American Society of Agronomy experienced the loss of one whose influence on agronomic affairs and especially those concerned with forage crops was widely felt. Though forced by ill health during recent years to forego active participation in the meetings of the Society, his interest in its affairs was always keen. He had been a member of the Society since 1910 and was elected a Fellow in 1927.

Dr. Oakley was born in Marysville, Kansas, September 7, 1880, and was graduated from the Kansas Agricultural College with the degree of B.S. in 1903. In 1920, Iowa State College awarded him the degree of D.Sc. Appointed Scientific Aid in the former Office of Grass and Forage Crop Investigations in 1903, he soon became the right hand of the late C. V. Piper and devoted himself intensively to the study of forage crops. His main interest, especially in his earlier years, was in alfalfa and he contributed alone or in association with others many bulletins and other papers on this crop. In 1913 he was placed in charge of seed distribution, which position he held until the discontinuance of this work in 1926. During this time, he maintained his connection with forage crop investigations.

Besides his work with alfalfa, Dr. Oakley's chief interest, especially during the later years, was in the study of fine turf grasses, in which he collaborated with Professor Piper. Together they laid the foundations for this work; interested the United States Golf Association and enlisted its financial assistance; established the Bulletin of the Green Section and built up the Section to a real influence for better turfs. He was co-author with Professor Piper of an important book on the subject, "Turf for Golf Courses".

As is often the case with capable men, Dr. Oakley's time was much taken up by services of an administrative nature and by committee work. He was long a member of the Federal Horticultural Board; served during the war as Chairman of the Committee on Seed Stocks; represented the Secretary of Agriculture in some delicate negotiations connected with an outbreak of foot and mouth disease in California, and in 1926 was appointed a special delegate from the United States Department of Agriculture to the International Institute of Agriculture at Rome. Just prior to this latter appointment, he succeeded C. V. Piper in charge of the Office of Forage Crops, Bureau of Plant Industry.

Long a sufferer from arthritis, he never allowed pain to subdue his spirit or to sour his character. He was always cheerful and one of the strongest impressions his friends have of him is the courage with which he bore his physical ills. Frail of body, his mind was active and clear and even when forced by increasing ill health to live in California, he maintained his interest in the work of the Department and carried on an active correspondence with members of its staff.

Dr. Oakley made a large contribution to the literature of agriculture in the form of Technical and Farmers' Bulletins and general agricultural papers published in various series of the United States Department of Agriculture and in numerous scientific and agricultural journals. A broad and original thinker, his counsel was much sought by his associates, and was freely and frankly given. A host of friends throughout the country regret his untimely passing.—A. J. Pieters.

Lucius Lincoln Van Slyke

Dr. L. L. VanSlyke died at his home in Geneva, New York, on September 30, 1931. He was seventy-two years of age at the time of his death and had retired

from active service at the New York State Agricultural Experiment Station two years before.

Dr. VanSlyke was a native son of New York State, and spent most of his life there. He did his undergraduate and graduate work at the University of Michigan, receiving his A.B. degree there in 1879, his A.M. in 1881, and the Ph.D. degree in 1882. He was an instructor in analytical chemistry at the University from 1882 to 1885. He then became Professor of Chemistry in Oahu College and government chemist for the Hawaiian Islands. In 1889, he returned to the University of Michigan for a year as instructor in general chemistry and in 1890 was appointed chief chemist at the New York State Agricultural Experiment Station at Geneva, which position he held for forty years.

Dr. VanSlyke was in charge of the inspection analysis laboratories at the Station from their establishment until his retirement, including all of the analytical work required for the operation and enforcement of the state feeding stuffs, fertilizer, and insecticide and fungicide laws. He had a very active part in the enactment and interpretation of these laws and a large part of their success was due to his intelligent and painstaking management of this part of the state's agricultural activities. He was for many years an active member, and a past-president, of the Association of Official Agricultural Chemists.

In his later years, Dr. VanSlyke's research was chiefly in the field of dairy chemistry, but his earlier studies with relation to fertilizer needs and uses and in the chemistry of insecticides and fungicides, contributed largely to the sound basis of agronomic science in America. His most important contribution in the field of agronomy was undoubtedly his well-known and widely-used text book on "Fertilizers and Crops." He was engaged in a new revision of this book at the time of his death.—R. W. THATCHER.

Respectfully submitted
F. D. KEIM
J. D. LUCKETT, *ex officio*
S. B. HASKELL, *Chairman.*

OFFICERS' REPORTS

REPORT OF THE EDITOR

J. D. Luckett, Editor, presented the following report which, upon motion, was adopted:

Volume 23 of the JOURNAL represents another year of somewhat conservative management of the publication affairs of the Society—conservative, that is, to the extent of holding the JOURNAL to a size that would permit still further retrenchment of the Society's finances. This has necessitated a rather rigid restraint on a natural impulse to move a large number of accumulated papers more rapidly than the 1,050- to 1,100-page limit placed on the 1931 volume would permit. We believe, however, that the best interests of the Society have been served by avoiding any considerable expansion of the JOURNAL during the past year.

The current volume, when it is completed with the December number, will compare favorably with the 1930 volume as to size and general content. It will contain 100 contributed papers, 9 notes, and 16 book reviews, in addition to numerous announcements and miscellaneous items of agronomic interest. We have 47 papers on hand at the present time. During the year, 28 papers were returned to their authors for one reason or another. These figures make a total of 200 contributions passing through the Editor's hands to date.

With the appearance of the December number, we shall have published all contributions accepted prior to May 15, 1931, indicating that an interval of approximately seven months elapses between date of acceptance and date of appearance of papers submitted to the JOURNAL under existing conditions.

During the year we have continued to develop a cumulative index to the JOURNAL which is maintained along with the index to the current volume. A cumulative index to the first 20 volumes, including the PROCEEDINGS, was published in 1928, and it is proposed to keep this index up to date with supplements issued at five-year intervals.

We regret to report that the outlook for advertising in the JOURNAL is not as favorable as it was at this time last year, for rather obvious reasons. However, we take pleasure in recording here our appreciation of the support of those advertisers who are patronizing the JOURNAL, and would urge that they receive every consideration from our readers. We would ask also for your personal solicitation of advertising for the JOURNAL, in the belief that a word from you, coupled with our own efforts, is most effective. Two valuable contracts now running in the JOURNAL are the direct outcome of personal solicitation of this sort.

In order to satisfy ourselves that the JOURNAL is being manufactured as economically as possible and still maintain certain standards of quality and workmanship, we have asked competent printers for estimates on the printing of the JOURNAL for 1932. These estimates will be laid before the Executive Committee with a recommendation as to the placing of the 1932 contract. It is apparent from the figures obtained that next year the JOURNAL will be printed at an appreciable saving over recent years.

A new editorial venture this year is the publication of abstracts of the papers to be presented at this meeting for distribution at the registration desk. This would seem to be well worth while. The abstracts are also to be made part of the proceedings of the annual meeting which appear as part of the December number of the JOURNAL.

We want to take this opportunity to call your attention to the exhibits in nearby rooms. All advertisers in the JOURNAL and a few others whose products we believed to be of special interest to members of this Society were invited to participate in the exhibit, with the result as you see it. We hope that these displays will add materially to the interest and value of the meeting.

We are deeply indebted to the several representatives of institutions scattered over the country who have kept us informed of items of interest to readers of the JOURNAL by supplying the copy that appears under the headings of "Agronomic Affairs" and "News Items". We feel that these sections are exceedingly worth while, and trust that we shall continue to receive your cooperation in keeping them alive.

And now, faced with an unprecedented number of papers to carry over to the new year, we must urge once again, and even more emphatically than in the past, the necessity for brevity in papers offered for publication in the JOURNAL. Very likely it will be impossible to increase to any great extent the number of pages in the 1932 volume, hence little, if any, relief of our congested publication schedule can be looked for in that direction.

Many technical journals set arbitrary limits on the length of manuscripts that they will accept—at least such limits are prescribed. In one case with which we are familiar it is 8 pages; in another 20 pages; in a third, the author pays for all pages of printed matter beyond the first six. Needless to say, this last journal enjoys a preponderance of short, pithy articles.

We do not want to set an arbitrary limit, but we do feel that in a journal operating under the resources available to the JOURNAL OF AGRONOMY, with its very considerable number of contributors, that 16 to 20 pages of manuscript should be an ample allowance for the great majority of papers submitted to us. The alternatives are increased dues to support a larger journal to print longer papers or ever-increasing delays in the publication schedule. We urge shorter papers as a happy medium.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE TREASURER

The Treasurer submitted his annual report, as follows, which was received and referred to the Auditing Committee:

I beg to submit herewith the report of the Treasurer for the year November 1, 1930, to November 1, 1931:

Balance, last report, General Fund		$1342.32
Balance, last report, Lime Association Fund		147.20
Total Balance, last report		$1489.52
RECEIPTS 1931		
Dues 1931	$3075.25	
Dues 1931 (new)	525.00	
Dues 1930	25.31	
Dues 1932	25.00	
Subscriptions 1931	1781.50	
Subscriptions 1931 (new)	431.25	
Subscriptions 1930	96.49	
Subscriptions 1932	13.50	
Advertising Income	1070.97	
Reprints Sold	747.62	
Journals Sold (index)	127.72	
Total Income 1931	$7919.61	$7919.61
Total Receipts + Income		$9409.13
DISBURSEMENTS 1931		
Printing the JOURNAL, reprints, etc. (September 1930–Sept. 1931 incl. 13 issues)	$7119.01	
Salary Business Manager	750.00	
Postage (Sec'y and Bus. Mgr.)	194.05	
Printing (miscellaneous, programs, etc.)	180.30	
Express on JOURNALS	29.81	
Mailing clerk	59.43	
Refunds, checks returned, etc	117.56	
Miscellaneous (badges, supplies, expenses of annual meeting, etc.)	315.43	
Total Disbursements 1931	$8765.59	$8765.59
Balance on hand		$ 643.54
Total Income		$9409.13
Total Disbursed		8765.59
Balance		$ 643.54
Balance in Lime Association Fund		$ 147.20
Balance in General Fund		496.34
Total		$ 643.54

Respectfully submitted,
P. E. BROWN, *Treasurer*.

Prof. George Roberts reported that the Auditing Committee had examined the books and vouchers of the Treasurer and found them correct. Upon motion the report was adopted.

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall presented the report of the Assistant Treasurer as follows, which upon motion was accepted with the understanding that the President would appoint someone in Washington to audit the account:

American Society of Agronomy in Account with the Executive Committee of the First International Congress of Soil Science November 1, 1930, to November 6, 1931

Receipts:		
Contribution to Endowment Fund	$1,000.00	
Sale of Proceedings of First Intern'l Congress of Soil Science (1927)	227.07	
Membership dues and initiation fees for International Society of Soil Science	938.40	
Interest on savings account with Prince Georges Bank and Trust Co., Hyattsville, Md	32.98	
	$2,198.45	
BALANCE on hand in bank as of Nov. 1, 1930	959.06	
		$3,157.51
Expenditures:		
Membership dues and initiation fees for International Society of Soil Science, transmitted to Dr. Hissink, General Secretary, of the Society	$ 938.40	
Postage for office correspondence (including mailing by parcel post of abstracts of Proceedings of First Congress, as well as remaining supply of Russian Pedological Papers left from First Congress, sent to various agricultural colleges in the U. S.)	35.00	
Office service	10.00	
The Rumford Press, for distribution of sets of Proceedings of First Congress, which includes transportation charges	62.35	
Premium on bond for Dr. A. G. McCall, treasurer	5.00	
Cablegram message to Dr. Hissink	1.80	
Bank exchange on foreign checks	1.67	
	$1,054.22	
BALANCE on hand in bank as of November 6, 1931 (inclus.)		
Savings account	$1,948.73	
Checking account	134.41*	
By bank's transfer of funds adjustment	20.15	
		$3,157.51

*Statement by Bank in letter dated Nov. 5, 1931, shows $135.53 as against $134.51 shown on their statement of Nov. 6, 1931, accounted for by $1.12 exchange fee on foreign check charged Nov. 6, 1931.

Orders for Proceedings of the First International Congress of Soil Science
Distributed through office of Dr. A. G. McCall
To November 2, 1931, inclusive.

Approximately:

Paid Orders

Sets at $5.00	488	$2,440.00
Sets at $10.00	316	3,160.00
Sets at $5.50	1	5.50
Sets at $10.50	1	10.50
		$5,616.00

Unpaid Orders

Sets at $5.50	1
Sets at $10.00	1
Sets at $11.50	1

Complimentary

Sets		228
Distributed total		1,037 Sets
Ordered from Rumford Press (Vol. I, II, III, IV)		2,000 sets
Ordered from Rumford Press (Vol. V only)		1,000 sets
Original order	2,000 sets	
Distribution as above	1,037 sets	
On hand in storage Rumford Press, Concord, New Hampshire	963 sets	

A. G. McCALL, *Exec. Secretary,*
American Organizing Committee.

REPORT OF THE SECRETARY

The report of the Secretary was read and, upon motion, was accepted, as follows:

I beg to submit herewith the report of the Secretary for the year November 1, 1930, to November 1, 1931:

Membership Changes 1930–1931

Membership, last report			943
New Members 1931		104	
Reinstated members		20	
Total Increase		124	
Dropped for N. P. D	75		
Resigned	25		
Died	4		
Total Decrease	104	104	
Net Increase		20	20
Membership, November 1, 1931			963

Subscriptions

Subscriptions, last report		525
New subscriptions	120	
Subscriptions dropped	80	
Net increase	40	40
Subscriptions November 1, 1931		565

MEMBERSHIPS AND SUBSCRIPTIONS BY STATES AND COUNTRIES

	Members	Subscriptions
Alabama	12	1
Arizona	11	1
Arkansas	7	3
California	30	10
Colorado	12	4
Connecticut	11	4
Delaware	7	2
District of Columbia	66	4
Florida	17	4
Georgia	18	3
Idaho	9	1
Illinois	43	17
Indiana	27	2
Iowa	36	6
Kansas	29	2
Kentucky	10	2
Louisiana	14	2
Maine	6	1
Maryland	16	5
Massachusetts	15	7
Michigan	18	4
Minnesota	22	5
Mississippi	6	2
Missouri	21	5
Montana	10	2
Nebraska	19	4
Nevada	1	2
New Hampshire	2	1
New Jersey	17	3
New Mexico	4	2
New York	46	21
North Carolina	14	2
North Dakota	16	1
Ohio	40	6
Oklahoma	16	4
Oregon	11	3
Pennsylvania	17	6
Rhode Island	4	0
South Carolina	10	1
South Dakota	10	1
Tennessee	8	5
Texas	34	7
Utah	13	6
Vermont	3	1
Virginia	22	2
Washington	8	4
West Virginia	9	1
Wisconsin	30	4
Wyoming	4	1
Alaska	4	1
Canada	31	40
Cuba	3	2
Hawaii	12	12
Philippine Islands	4	4
Porto Rico	2	3
Africa	6	38
Argentina	8	7
Australia	3	25
Bolivia	1	0
Brazil	2	1
British Guiana	0	1
British West Indies	1	1
Ceylon	0	2
China	8	21
Colombia	1	0
Czecho-Slovakia	0	1
Denmark	1	1
Dominician Rep.	1	0
Dutch East Indies	0	2
Egypt	2	2
England	5	11
Estonia	0	1
Fed. Malay Sta.	0	2
Fiji	0	2
Finland	0	2
France	0	7
Germany	4	7
Greece	1	0
Haiti	0	1
Holland	0	2
Honduras	2	1
India	3	17
Ireland	0	2
Italy	1	6
Japan	5	71
Jugoslavia	1	2
Mauritius	0	1
Mesopotamia	1	1
Mexico	2	1
Norway	1	1
Peru	3	1
Poland	1	1
Portugal	0	1
Roumania	0	2
Scotland	0	3
South Wales	0	1
Spain	0	1
Sweden	2	4
Switzerland	1	0
Turkey	1	1
Uruguay	0	1
U. S. S. R.	7	59
Wales	1	1
Totals	963	565

MEMBERS BY YEARS

1908 Charter	31
1908	9
1909	5
1910	13
1911	22
1912	12
1913	15
1914	12
1915	19
1916	32
1917	15
1918	11
1919	14
1920	27
1921	44
1922	43
1923	28
1924	40
1925	75
1926	59
1927	66
1928	75
1929	105
1930	87
1931	102
1932	2
Total	963

TOTAL MEMBERSHIP BY YEARS

1908	121	1916	586	1924	577
1909	129	1917	652	1925	646
1910	176	1918	509	1926	700
1911	236	1919	473	1927	767
1912	295	1920	436	1928	823
1913	349	1921	592	1929	906
1914	397	1922	643*	1930	943
1915	471	1923	561	1931	963

*In 1922 the dues were increased to five dollars.

Respectfully submitted,
P. E. BROWN, *Secretary.*

FELLOWS

The Fellows elected were announced by Vice-President R. I. Throckmorton (pages 1018 to 1020). Those receiving this honor were Dean W. W. Burr, Prof. F. D. Gardner, Dr. M. A. McCall, Prof. Charles F. Shaw, and Dr. W. H. Stevenson. Diplomas were presented.

CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARDS

Dr. Richard Bradfield, Chairman of the Committee on the Chilean Nitrate of Soda Nitrogen Research Award, announced that in spite of present conditions the Chilean Nitrate of Soda Educational Bureau had arranged for two five hundred dollar awards. The Committee had carefully considered all nominees for the award and had unanimously agreed to the following: Dr. W. H. Pierre of the West Virginia Agricultural Experiment Station and Dr. Hans Jenny of the University of Missouri.

In presenting the diplomas, Dr. Bradfield said in part, as follows:

The Educational Bureau of the Chilean Nitrate Company set aside this year the sum of $1,000 for their Nitrogen Research Award. This award has as its object the recognition and encouragement of research on any of the diverse aspects of the rôle of nitrogen in economic crop production. It is administered by a standing committee of the American Society of Agronomy. This year's award was divided equally between Dr. W. H. Pierre of the Dept. of Agronomy of the University of West Virginia and Dr. Hans Jenny of the Dept. of Soils of the University of Missouri.

The award to Dr. Pierre was made in recognition of his work on the effect of the various nitrogenous fertilizers on soil reaction. His work has clearly shown that the continued use of $(NH_4)_2SO_4$ on light, poorly buffered soils will develop within a few years a degree of acidity which is distinctly harmful to many crops. Similar effects are not obtained with the other common nitrogen fertilizers. By supplementing $(NH_4)_2SO_4$ with sufficient lime satisfactory results may be obtained.

The award to Dr. Jenny was made in recognition of his work on the effect of climate on the nitrogen content of soils. By a careful correlation of climatic data and of the thousands of nitrogen determinations made on the soils of America, Dr. Jenny has been able to develop an equation of state which shows the general relationship existing between the stable nitrogen content of soils and temperature and rainfall which are the principal climatic factors affecting it.

The awards were announced at the Annual Banquet of the American Society of Agronomy held in Chicago on November 19. In addition to the cash awards the winners were also presented with an appropriate certificate by the American Society of Agronomy.

Meeting adjourned.

P. E. Brown, *Secretary.*

OFFICERS OF THE SOCIETY FOR 1932

P. E. Brown
President
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F. B. Smith, *Secretary-Treasurer*
Ames, Iowa

J. D. Luckett, *Editor*
Geneva, N. Y.

ABSTRACTS OF PAPERS PRESENTED AT THE ANNUAL MEETING

SYMPOSIUM ON "RELATION OF CALCIUM AND MAGNESIUM COMPOUNDS TO SOIL CONDITIONS AND PLANT GROWTH"

LEADER: A. B. BEAUMONT, *Massachusetts State College.*

1. **Conditions and Practices Affecting the Outgo of Calcium and Magnesium from Soils.** J. A. BIZZELL, *Cornell University.* Discussion led by W. H. MACINTIRE, *University of Tennessee.*

2. **The Effect of Liming Soils on the Availability of Manganese and Iron.** L. G. WILLIS, *North Carolina State College of Agriculture.* Discussion led by T. E. ODLAND, *Rhode Island State College.*

3. **Relation of Calcium and Magnesium to the Growth and Quality of Tobacco.** J. E. MCMURTREY, JR., *U. S. Dept. of Agriculture.* Discussion led by M. F. MORGAN, *Connecticut State Agricultural Experiment Station.*

4. **The Effect of Magnesium Deficiency on the Growth of Potatoes.** J. A. CHUCKA, *University of Maine.* Discussion led by A. B. BEAUMONT, *Massachusetts State College.*

5. **The Function of Calcium in the Growth of Certain Legumes.** W. A. ALBRECHT, *University of Missouri.* Discussion led by J. K. WILSON, *Cornell University.*

6. **The Importance of Calcium and Magnesium to the Nitrogen and Fertilizer Industry.** F. W. PARKER, *E. I. duPont de Nemours & Co.* Discussion led by J. P. JONES, *Koppers Research Corp.*

7. **The Toxic and Antagonistic Action of Magnesium.** W. S. EISENMENGER, *Massachusetts State College.*

8. **The Relation of Native and Applied Calcium and Magnesium Compounds to the Availability of Potassium.** W. H. MACINTIRE, *University of Tennessee.* Discussion led by E. TRUOG, *University of Wisconsin.*

9. **Available Calcium and Magnesium in Relation to Phosphate Utilization.** E. TRUOG, *University of Wisconsin.* Discussion led by C. E. KELLOGG, *North Dakota Agricultural College.*

1. Conditions and Practices Affecting the Outgo of Calcium and Magnesium from Soils.—J. A. BIZZELL, *Cornell University.*

Lysimeters were filled with Dunkirk fine sandy loam and subjected to different fertilizer treatments and cropping systems during a period of 9 years.

In one experiment ammonium sulfate was compared with sodium nitrate. Two crops were grown each year. Lettuce and beets alternated with spinach and carrots. Ammonium sulfate caused a greater total removal and a higher concentration of calcium than did sodium nitrate. The concentration appeared to be independent of the total drainage flow. The crops also showed a higher calcium content following the ammonium sulfate treatment.

In the second experiment the soil received no nitrogen except that contained in manure. Ordinary field crops were grown in regular rotation on some of the lysimeters, while others were kept free of all vegetation. Cropping decreased the total calcium removal in the drainage, but the concentration was not materially altered.

Comparing the vegetable crop system receiving ammonium sulfate and sodium nitrate with the field crop rotation receiving nitrogen only in manure, the following average results were obtained:

Treatment	Total Ca in drainage in pounds per acre, annual average	Average concentration of Ca in drainage in p.p.m.
Ammonium sulfate Sodium nitrate	322.0	85.5
Manure	200.0	50.3

2. The Effect of Liming Soils on the Availability of Manganese and Iron.—L. G. WILLIS, *North Carolina State College of Agriculture.*

The availability of soil manganese to plants is governed by the solubility which is controlled by several factors, the most important being the reaction and the oxidation-reduction potential.

The steps by which manganese becomes unavailable are the conversion of the bivalent forms into the hydroxide and carbonate and subsequent oxidation to the dioxide. Soils containing limited amounts of total manganese, if limed to a pH value of 6.4 or higher under oxidizing conditions, may show a deficiency of manganese for plants requiring relatively large amounts of manganese. Soil factors causing limited root development may contribute to the deficiency.

Control of manganese deficiency in soils of low total manganese content may be accomplished by limiting the rate of liming so that pH values of 6.4 are not exceeded or, where a less acid soil is required, by fertilization with manganese sulfate. Reducing conditions and soil acidity are favorable to the maintenance of an adequate supply of manganese.

Liming at rates to produce pH values of the soil less than 7.9 is not likely to produce a deficiency of iron for plants except where the con-

current absorption of lime by the plant causes physiological disturbances that make the iron less efficiently utilized.

In the presence of strong oxidants, such as manganese dioxide, the reaction at which symptoms of a deficiency are produced may be as acid as pH 6, although there is no certainty that the effect in such cases is not accentuated by the absorption of abnormal quantities of manganese.

The liming of reductive soils may increase the solubility of iron by decreasing the soil potential, thus converting the iron to the more soluble ferrous condition.

There is no satisfactory evidence that a deficiency of iron is solely responsible for the symptoms shown by susceptible crops, such as pineapples, rice, and some trees, except as a possible reduction in the concentration of soluble iron in the soil consequent to liming is associated with an unfavorable effect of the lime or other soil component on the assimilation or translocation or utilization of the iron by or in the plant.

It is difficult to control iron deficiency by fertilization with iron compounds. Spraying or injection methods are generally successful.

Soil conditions which may be governed by reaction alone or in conjunction with a high degree of oxidativeness may reduce the iron content of forage plants to a point below the amount adequate for the support of livestock without reducing yields. This type of deficiency may be controllable by fertilization with an iron salt.

3. Relation of Calcium and Magnesium to the Growth and Quality of Tobacco.—J. E. McMurtrey, Jr., *U. S. Dept. of Agriculture.*

When only nitrogen, phosphorus, and potassium are supplied in the fertilizer on some soils the growth of the tobacco plant exhibits definite pathological symptoms and growth is decidedly reduced. The addition of magnesium results in some increase in growth, but the growth still may be abnormal. This abnormality consists of development of upper leaves of the plant in which the tips and margins are partly missing. This gives these leaves a cut-out appearance. The plant as a whole shows a dark green color and in the later stages the terminal bud dies. This condition is corrected by the addition of calcium and may be considered as typical of calcium deficiency. The addition of calcium alone to the mixture supplying nitrogen, phosphorous, and potassium results in characteristic symptoms of magnesium hunger which are typified by a breaking down of the chlorophyll. This chlorosis begins on the lower leaves of the plant and at the tips of the affected leaves.

It appears that the leaf tissues should contain more than 1% of calcium to prevent symptoms of its shortage. The requirement for prevention of symptoms of magnesium deficiency is a content of around 0.25% magnesium in the dry leaf. These requirements have been met by furnishing in suitable forms 35 pounds of calcium and 12 pounds of magnesium per acre on the soils in question. However, when dolomitic limestone was the source of magnesium, it was necessary to supply considerably larger quantities. This material has not given satisfactory results with tobacco under all conditions.

Where farm manure and other organic materials of plant or animal origin have been used extensively as fertilizers a shortage of calcium and magnesium has not been apparent. The extensive use of superphosphate or other calcium phosphates as constituents of standard fertilizer mixtures has avoided any danger of loss of production from acute shortage of calcium.

4. The Effect of Magnesium Deficiency on the Growth of Potatoes.— J. A. Chucka, *University of Maine.*

During the last few years a "potato sickness" resulting in a stunted and chlorotic appearance of the plants has given potato growers considerable trouble on some of the extremely acid and worn-out soils of Maine. In extreme cases this condition has resulted in almost complete crop failures. A study of this problem in 1930 indicated that this "potato sickness" could be prevented by the addition of magnesium to potato fertilizers. That year an application of 300 pounds per acre of magnesium sulfate containing an equivalent of 51 pounds of magnesium oxide resulted in the production of healthy plants and increased the yield from 173.4 to 328.1 bushels per acre.

In 1931 varying amounts of magnesium in the forms of epsom salts, double sulfate of potash-magnesia, and hydrated dolomite were used with a standard potato fertilizer with and without lime. These treatments were replicated four times on three different farms which were chosen to represent average soil conditions in Aroostook County.

Field observations during the growing season indicated that all of the magnesium-treated plats were free from the chlorotic appearance. All forms and amounts of magnesium gave increased yields over check plats without magnesium. The lowest application, namely, 100 pounds of magnesium sulfate (17 pounds MgO) was more effective in increasing potato yields than the higher applications. The results indicated that higher amounts of magnesium could be used in the form of double sulfate of potash-magnesia than in the form of epsom salts and also that the higher applications were more effective when lime was used with them. The increased yields for 1931 due to addition of magnesium ranged from 3.2 to 36.1 bushels per acre.

5. The Function of Calcium in the Growth of Certain Legumes.— W. A. Albrecht, *University of Missouri.*

The failure to obtain a better growth of legumes on acid soils raises the question whether liming functions by removing the excessive hydrogen ions or by supplying the deficient calcium ions. Observations and experiments pointed out that small amounts of calcium as carbonate, hydroxide, chloride, acetate, and nitrate influenced the nodulation of soybeans as much as 300%. This effect was manifested through the plant and not the bacteria, since transplanting 10-day-old seedlings from sterile, calcium-bearing sand to sour soil, already inoculated, increased nodulation four times over plants from untreated sand. This test also suggested greater nitrogen

absorption and greater fixation through the influence of calcium carried in the transplanted seedling.

Electrodialyzed colloidal clay, titrated to various degrees of saturation, as a means of supplying calcium at varying degrees of acidity and used in different amounts per seed to supply variable amounts of available calcium, served to show that disease-free, apparently normal growth of the soybean is controlled by the amount of available calcium and not by the hydrogen-ion concentration within the more common but not extreme ranges of the latter. This effect was limited to the ionic or adsorbed forms. Mineral crystal calcium was without effect. Potassium and magnesium failed to function in this respect as did calcium. At low supplies of calcium per plant, no nodulation was possible; with higher supplies, both growth and nodulation resulted.

The data obtained suggest that the function of calcium in the growth of legumes is not one of changing the soil reaction, but one of supplying the element calcium, that seems to be a greater requisite than other elements for the growth, nodulation, and normal development of legumes.

6. The Importance of Calcium and Magnesium to the Nitrogen and Fertilizer Industry.—F. W. PARKER, *E. I. du Pont de Nemours & Co.*

The nitrogen and fertilizer industries are interested in seeing that their products are used with maximum economy and efficiency and that this efficiency is not impaired by the lack of any of the so-called minor elements of which calcium, magnesium, and sulfur are the most important. The evidence indicating the importance of some of the minor elements in crop production and fertilizer practice is discussed briefly.

Associated with the calcium and magnesium problem is the question of the influence of fertilizers, particularly nitrogenous fertilizers, on soil reaction. The available data show that in good fertilizer practice provision should be made for the addition of calcium, magnesium, and sulfur to the soil, and that the fertilizer practice should be such as will not cause an increase in soil acidity, except under special conditions. The addition of the minor elements and control of the acid-forming tendency of fertilizers is most important on the soils of the Gulf and Atlantic Coastal Plains.

In light of the requirements of good fertilizer practice, consideration is given to the relative merits of ammonium and calcium phosphates, ammonium and nitrate sources of nitrogen, and the use of dolomitic limestone in fertilizers. The conclusion is reached that from the standpoint of good fertilizer practice and economy to the consumer the calcium phosphates are preferable to the ammonium phosphates. Likewise, ammonium sources of nitrogen used with dolomitic limestone are more economical and preferable to nitrate sources of nitrogen. Finally, the use of dolomitic limestone in complete fertilizers and mixed with ammonium sulfate for top-dressing is advocated as a means of adding adequate amounts of calcium and magnesium to soils and preventing the fertilizers from increasing soil acidity.

7. The Toxic and Antagonistic Action of Magnesium.—W. S. EISENMENGER, *Massachusetts State College.*

Magnesium with respect to its solution tension and its relative abundance in the soil is less toxic than most of the other elements. With respect to the toxicity as compared with other elements of the same class as calcium, sodium, and potassium it is more toxic at moderate and high concentrations. At extremely low concentrations the magnesium ion is less toxic than calcium, sodium, and potassium.

The appearance of poisoned wheat plants would indicate that toxic effects of each ion were specific in nature. Different anions of magnesium, such as $MgSO_4$, $Mg(NO_3)_2$, and $MgH_4(PO_4)_2$, when employed in single salt solutions, do not indicate wide differences in toxicity. Present-day concepts of antagonism indicate that cations form complex compounds with the protoplasm or part of the protoplasm and that an undue replacement of one cation by another leads to pathological symptoms.

The cations K^+, Mg^+, and Ca^+ as salts in aqueous solutions and in pairs afford a growth over a wide range of concentration better than any one salt. Calcium is slightly superior as a factor in overcoming toxicity of each of the other two salts.

In farm practice there seems to be a close relationship between magnesium and phosphate availability. Dolomitic limes have a slight superiority over calcium limes in field tests, both as to yield and nitrogen accumulation.

8. The Relation of Native and Applied Calcium and Magnesium Compounds to the Availability of Potassium.—W. H. MACINTIRE, *University of Tennessee.*

It is pointed out that the supposed liberation of soil potassium has long been assigned as one of the beneficial effects of liming. A review of the earlier work at the Pennsylvania Experiment Station is given to show that an erroneous interpretation was drawn from the soil and crop analyses. The repressive effect induced by light limings upon the solubility of native potash supplies is shown by lysimeter findings at the Tennessee Experiment Station. The same effect by excessive quantities of seven liming materials for both soil and subsoil potash is also shown. The repressive effect of full-depth incorporations for Virginia and Tennessee soils is contrasted with the lower-zone effect of surface-zone incorporations of four liming materials over a 4-year period.

The repressive effect of high-calcic limestone upon the native potash compounds and the diminished outgo of simultaneous additions of soluble potash additions is shown for mixtures of Tennessee and Colorado soils. The residual effect of single additions of liming materials after a period of 12 years is shown for additions of soluble potash during the thirteenth and fourteenth years. It is also pointed out that large quantities of neutral calcium and magnesium salts have no capacity to effect an exchange for potassium when the neutral salts are supplemented by liming materials.

The fate of 82 annual additions of potash on the heavily limed Rothamsted soils and the transition of the potassium accumulates into non-exchangeable forms is linked with the other data to explain the several series of studies on potash solubility as influenced by liming.

Further evidence as to an absorption of potassium by plants grown on limed soils is given to show the practical aspect of the problem.

The difference between the effect of lime on soils that had reached the acidoid state and those that have not become acid is stressed.

The greater loss of Ca and Mg and the accumulation of potash compounds and the subsequent accumulation of hydrogen ions during the process of soil formation are cited to show that the minimum losses of potash occur during alkaline conditions. The replacement of hydrogen ions to the exclusion of potassium ions, the protective effect of Ca and Mg complexes formed by liming materials, and the transition of the added potash to non-replaceable, or pseudo-mineral, forms are discussed as accounting for the results found in the several studies.

9. Available Calcium and Magnesium in Relation to Phosphate Utilization.—E. Truog, *University of Wisconsin.*

We have accumulated considerable evidence tending to show that for the most effective use of rock phosphate as a fertilizer it is essential that there be present in soils an adequate supply of readily available magnesium. One of the well-recognized functions of magnesium is that it acts as a phosphorus carrier in plant metabolism. This being the case, the relationship just mentioned is readily explained.

When superphosphate is used as a fertilizer, the calcium sulfate which it contains tends to make magnesium available as the readily soluble sulfate, either by replacement in the exchange compounds or else by reaction with magnesium carbonate, if that is present. A deficiency of soluble magnesium, therefore, does not appear so quickly when superphosphate is used as when rock phosphate is used. The use of superphosphate, of course, does add small amounts of readily soluble magnesium and makes possible a more complete depletion of what little may be present in the soil.

Not only is it essential that plants be supplied with sufficient readily available magnesium, but is it also essential that there be a proper balance between easily soluble calcium and magnesium. This balance varies greatly with different species of plants, the legumes in general being favored with a high ratio of calcium to magnesium, while with cereals the ratio is low. When plants feed on rock phosphate they are largely forced to absorb an equivalent amount of calcium, thus disturbing the balance unless easily soluble magnesium is abundant. The use of pure calcium limestone tends further to unbalance the situation. On the other hand, the use of dolomitic limestone should tend greatly to ameliorate the difficulty and thus make the use of the rock phosphate more effective.

JOINT SYMPOSIUM ON "SOIL ORGANIC MATTER AND SOIL CLASSIFICATION"

American Society of Agronomy
and
American Soil Survey Association

LEADER: SELMAN A. WAKSMAN, *New Jersey Agricultural Experiment Station.*

1. **The Importance of Organic Matter in the Classification of Soils.** C. F. MARBUT, *U. S. Dept. of Agriculture.*
2. **Organic Matter as a Factor in Classification of the Soils of Dry Regions.**—C. F. SHAW, *University of California.*
3. **Distribution of Organic Matter and Nitrogen in the Profiles of Central Grassland Soils.** J. C. RUSSELL and M. D. WELDON, *University of Nebraska.*
4. **The Significance of Climatic Factors in the Regional Distribution of Organic Matter in Soils.** H. JENNY, *Univer ity of Missouri.*
5. **Classification of Peat Soils.** A. P. DACHNOWSKI-STOKES, *U. S. Dept. of Agriculture.*
6. **The Rôle of Organic Matter in the Classification of Forest Soils.** M. F. MORGAN and H. A. LUND, *Connecticut State Agricultural Experiment Station.*

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1. The Importance of Organic Matter in the Classification of Soils.— C. F. MARBUT, *U. S. Dept. of Agriculture.*

Soils must be classified on the basis of their characteristics. These characteristics are physical, chemical, and biological. The actual classification must be done in the field and on the basis of field characteristics, which are mainly physical.

Chemical characteristics are highly important but mainly valuable as a basis for the explanation of field characteristics. The organic matter of the soil is a highly important constituent because of its influence in determining both physical and chemical characteristics of the soil. It becomes, therefore, a feature that must be given consideration in classification. It is, however, only one of the constituents of the soil and can be given no more weight than that fact warrants.

In classification, both quantity and character of the organic matter in the soil are considered. Along with quantity the distribution of soil organic matter in the soil is given full consideration. This has its greatest importance in the grouping of soils into broad groups. This grouping must be based largely on the features of the virgin soil.

Up to the present time the quantity and distribution within the soil of the organic matter seem to give a basis for the grouping of soils into three great groups. In each of these groups there are several subgroups. The groups and subgroups are described.

The character of the organic matter is equally, if not even more important, than the quantity in soil grouping. The two characteristics in a broad way are closely related and interdependent. From the point of view of the soil morphologist and taxonomist, the character of the organic matter expresses itself in the physical character of the soil.

The morphologist must depend on the chemist and biologist to supply him with a basis for the explanation of the physical character. This explanation can be obtained by the chemists and biologists only on the basis of material selected by the morphologist. The classification must be made by the morphologist.

In a broad way the character of the soil organic matter is of two kinds, which are described.

The study of soils up to the present time by the method of geographic correlation shows the following:

1. That quantity of soil organic matter depends on its character.
2. That the character of soil organic matter depends on (a) the character of the mineral constituents of the soil, (b) the character of the original vegetation, (c) the character of the environment in which the soil developed or is developing, and (d) the stage in development of the particular soil.

2. Organic Matter as a Factor in Classification of the Soils of Dry Regions.—CHAS. F. SHAW, *University of California.*

Measurements of the color characteristic of many soils of California show that there is a broad general correlation between the amount of rainfall and the color of the soil. The soils of the moister coastal regions and of the higher mountain slopes are darker than those of the interior valleys and of the desert regions. However, when a closer study is made comparing soils representing gradations in environmental influences of climate, the correlation becomes very poor. This held true regardless of cover, whether trees, brush, grass, or scattered herbs.

Treating the soil with H_2O_2 destroyed a major portion of the organic matter content and bleached the soils. Measurements were made of the color of the natural soil and of the bleached soil to determine the loss in "blackness." This loss, or degree of bleaching, did not correlate with the loss of organic matter occasioned by the H_2O_2 treatment, nor with the content of organic matter as calculated from the nitrogen content of the soil. Neither did it correlate with the mean annual precipitation, with mean temperature, nor with the "rain-factor" of Lang.

In the arid and semiarid regions, and especially where the precipitation is periodic with dry hot summers, organic matter plays a relatively minor part in determining the characteristics of soil profiles, its influence being limited mainly to the factor of color. During the dry season the organic mat, the surface soil, and upper subsoil become thoroughly dried out and the processes of bacterial decomposition decrease in intensity while oxidation is increased. During the winter and spring, the period of wet soils, decomposition is active. The organic debris disappears very rapidly, the "duff" and

"humus" of the forest floor is very limited in depth and quantity and the organic content of the mineral horizons is low. Organic matter does not accumulate in the normally well-drained soils of this region. Experiments in green manuring show that there is little "building up" of the organic matter content, although the use of green manures materially increases the growth and yield of crops.

In California, and in most arid regions, organic matter occupies a minor place in determining soil characteristics. Of much more importance are the mineralogical composition of the parent material; the degree of oxidation of the metals, especially iron; the intensity of leaching; and the extent of downward migration and subsoil accumulations of colloidal clays and cementing materials.

3. Distribution of Organic Matter and Nitrogen in the Profiles of Central Grassland Soils.—J. C. RUSSELL and M. D. WELDON, *University of Nebraska.*

A study has been made of the organic matter, nitrogen, and ammonia-soluble humus content of grassland soils from Michigan, Minnesota, South Dakota, Nebraska, Kansas, Oklahoma, Wyoming, and Montana. Organic matter contents were found to vary from over 10% in one Minnesota area to about 3% in a southwestern Kansas area and 2% in a Wyoming area. Nitrogen varied correspondingly.

The color of the surface soil was found to correlate in a broad way with organic content, however a study of the color of humus extracts revealed interesting differences. The humus of central Nebraska soils is blacker than that of western Nebraska and Wyoming soils, and the humus of northern areas is blacker than that of southern. The humus of the second 6 inches is generally blacker than that of the first 6 inches. There is some indication that the humus of a central north by south region transecting the grass lands is darker in color than that of soils to the east or west. The extreme variation in intensity of humus color in solutions of equivalent concentration may be as much as 100% between the gray soils of Wyoming and the black soils of Dakota.

Data on the organic matter and nitrogen content of several profiles by sections show the importance of taking into consideration the depth of sampling in making comparisons of organic matter and nitrogen between different regions.

The significance of the investigation in the zonal classification of soils is discussed.

4. The Significance of Climatic Factors in the Regional Distribution of Organic Matter in Soils.—H. JENNY, *University of Missouri.*

Discussion as to what extent the organic matter climate relation can be used for soil classification purposes (causality problem). Advisability of dividing the Chestnut soils, Chernozems, and Prairie soils into sub-groups according to temperature. Tentative characterization of climatic soil types on the basis of their nitrogen content.

5. The Classification of Peat Soils.—A. P. DACHNOWSKI-STOKES, *U. S. Dept. of Agriculture.*

The successive phases through which the classification of peat soils is passing are described. Certain aspects in the development of peat soils of widely differing character are pointed out, with special reference to profiles of peat areas in northern Minnesota, Wisconsin, and Michigan. In these profiles the effects of major processes of peat soil formation are recognized, together with morphological characteristics determined by past environmental conditions.

A systematic grouping of peat soils, however, requires more progress, both in the chemical analysis of type profiles and in studies upon micro-organisms causing changes in the various organic complexes of plant remains.

6. The Rôle of Organic Matter in the Classification of Forest Soils.—M. F. MORGAN and H. A. LUNT, *Connecticut State Agricultural Experiment Station.*

The most conspicuous feature of northern forest soils is the accumulation of organic debris upon the surface, the annual increment amounting to some 2,000 to 5,000 pounds per acre. The absence of black color in the mineral horizons would lead one to believe that forest soils contain less organic matter than do prairie soils; yet analyses reveal little or no difference in he total amount, approximating 200,000 to 500,000 pounds per acre in both cases. The chief differences between the organic matter of forest and prairie soils are in its character and vertical distribution. The carbon-nitrogen ratio of the organic matter of forest soils is much wider than in prairie soils.

Organic analyses of the A and B horizons of North Dakota tschernosem, made by Waksman and Stevens, when compared with those made on a white pine forest profile from Keene, New Hampshire, reveal a higher content of water-soluble and alcohol-soluble material and a lower content of cellulose in the A and B horizons of the forest soil than in the corresponding horizons of the prairie soil.

The B horizon of a well defined forest podsol profile, although coffee brown or rust brown in color, frequently contains a higher percentage of organic matter than does the black A horizon of a prairie soil.

The organic material in forest soils has a pronounced effect upon the volume weight, when contrasted with tschernosem soils, as is shown below:

Tschernosem		Forest Soil	
Loss on ignition	Volume weight	Loss on ignition	Volume weight
4.17	1.358	3.9	1.297
5.96	1.318	5.5	1.116
7.08	1.248	6.6	1.047
10.94	1.143	11.5	0.890
13.24	1.135	14.4	0.837

The typical vertical distribution of organic matter of forest soils is as follows:

Total organic matter in pounds per acre.

	Thick podsol Waterville, N. H.	Thin podsol Union, Conn.	Rich crumb mull Bethlehem, N. H.	Crumb mull Groton, Conn.
Litter	—	—	13,664	3,774
F	18,674	6,173	—	—
H_1	105,840	60,768	—	—
H_2	32,414			
A_1	—	—	336,771	29,397
A_2	17,404	11,766		107,474
B_1	29,099	27,934	131,757	54,430
B_2	286,599	145,697		16,400
C_1	64,422	18,743	33,037	11,152
Total	554,450	271,081	515,231	222,627

Forest soil organic matter is further characterized by its strong acidity. The type of vegetation has a marked influence, coniferous needles and the leaves of ericaceous shrubs forming raw humus attaining a pH as low as 3 or even lower. It is difficult to conceive of any simple organic acid capable of producing this degree of dissociation.

The reaction of the A_2 of a well-developed podsol is usually about the same as that of the H layer, while the B horizons become less acid with depth.

SYMPOSIUM ON "COLD AND DROUTH RESISTANCE IN PLANTS"

LEADER: R. I. THROCKMORTON, *Kansas State Agricultural College.*

1. **The Biochemical Basis of Winterhardiness and Drouth Resistance.** J. H. MARTIN, *U. S. Dept. of Agriculture.*
2. **Cold Resistance in Corn.** J. R. HOLBERT and W. L. BURLISON, *University of Illinois.*
3. **Relation of Winterhardiness to Distribution of Crop Plants.** S. C. SALMON, *U. S. Dept. of Agriculture.*
4. **Influence of Temperature, Light, and Moisture on Hardening Processes in Alfalfa.** H. M. TYSDAL, *U. S. Dept. of Agriculture.*
5. **Artificial Refrigeration as a Means of Studying Winterhardiness.** R. B. HARVEY, *University of Minnesota.*

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1. The Biochemical Basis of Winterhardiness and Drouth Resistance.—J. H. MARTIN, *U. S. Dept. of Agriculture.*

Water is the most abundant constituent of growing plants. Both winterhardiness and drouth resistance are concerned, primarily, with water relations. Drouth resistance consists of either the retention and absorption of water under conditions of limited moisture and high evaporation, or the ability of a plant to absorb water and recover after wilting has taken place. Winterhardiness consists largely of the ability of a plant to retain water in its protoplasm against the force set up in the formation of ice crystals and to prevent the disorganization of the plant cells by low temperatures or ice formation.

Winterhardy varieties of a plant tend to have a lower moisture content, higher concentrations of solids and bound water in the cell sap, a lower rate of respiration at low temperatures, and a greater ability to elaborate hydrophilic colloids than do non-hardy varieties.

Drouth-resistant plants may have a high osmotic cell-sap concentration, or a high imbibition pressure and a high content of bound water, due to abundant colloidal material in the protoplasm. In crop plants, structural characteristics which retard evaporation, together with the ability of the plants to undergo dormancy and to regulate growth and fruiting according to the available moisture supply, probably are much more important in determining drouth resistance than chemical characteristics of the cell sap.

In the sorghum plant the juices of leaves and internodes in different positions on the stalk show distinct differences in composition. Bottom and top leaves lose water more rapidly than middle leaves. The tip of a leaf loses water more rapidly than the base.

2. Cold Resistance in Corn.—J. R. HOLBERT AND W. L. BURLISON, *University of Illinois.*

Frost in the late spring, or in the early fall before the corn is fully matured, is one of the great hazards of the corn crop. Almost every fall there is a period of a few days to more than 2 weeks when the

night temperatures drop below 50° F. This cool period usually is ended by still colder nights, the effects of which are described popularly as light frost, heavy frost, or killing frost. Frequently, the colder period is followed by several days or weeks of warmer weather, favorable for normal ripening of uninjured corn.

Some strains are injured by a succession of cool nights, during which the temperature drops only to about 50°; while other strains are killed by a few hours of exposure at temperatures around 40°. Although some strains may not actually be killed by such temperatures, their maturing often may be slowed down sufficiently to reduce the yield and quality of the grain.

Corn from plants killed prematurely by cold not only is inferior in quality but also is more susceptible to stalk breaking and to ear rots. Thus, there frequently is much commercial damage to the crop when the temperature falls below 40° for a few hours before maturity, even if there is no actual frost.

The results of cooperative studies on the problem for 8 years, during the last 4 years of which field refrigeration chambers have been used, indicate that:

1. Inbred, crossbred, and open-pollinated strains of corn differ widely in their resistance to injury from untimely chilling and freezing temperatures, both in the spring and in the fall.
2. The reaction of any particular strain is influenced by a number of factors, such as soil fertility, soil moisture, relative humidity, and rate of drop in temperature.
3. Corn grown on more productive and better-balanced soils is distinctly higher in cold resistance.
4. Plants injured by cold in the spring are less resistant to injury from heat and drouth.
5. The leaf, stem, and shank tissues of strains high in resistance to cold have greater water-retaining capacities than do comparable tissues of strains more or less susceptible to cold injury.
6. Tissue fluids of the more resistant strains are usually higher in total solids and in freezing point depression than are tissue fluids of the more susceptible strains.
7. Corn grown from seed selected from plants injured by cold prior to maturity is likely to have less resistance to injury from unfavorable soil and weather conditions in the young plant stage than corn grown from seed selected from comparable plants that have matured without cold injury.

The viability and value of seed of some strains of corn may be seriously affected by exposure to temperatures of 20° to 23°F, even with a moisture content of 18 to 20%.

3. Relation of Winterhardiness to the Distribution of Crop Plants.—
S. C. Salmon, *U. S. Dept. of Agriculture.*

Merriam, Livingston, Baker, and others have shown that fairly definite relations exist between the northern limit of crop plants and certain temperature factors during the growing season. In the case of the winter grains, the writer has shown that winter temperature

seems to be a determining factor. In the present paper, an attempt is made to relate the distribution of certain varieties of winter wheat and of alfalfa to ability to survive cold winters.

The relations which appear to be established should be of interest not only in relation to the general problem of crop distribution, but also in relation to crop improvement or crop breeding. It is obvious, of course, that a variety which produces high yields under favorable conditions may be of little or no value if it easily winter kills in severe winters. But winter killing is highly variable; so much so, in fact, that field tests as ordinarily conducted do not furnish the necessary information unless continued for a great many years.

Considerable progress has been made in devising special tests (field and laboratory) by means of which the relative resistance of varieties to winter killing or to low temperature may be determined in a very short time. Such determinations have been very helpful in predicting the geographical limitations of new varieties and strains, of which little was known concerning their adaptation.

4. Influence of Light, Temperature, and Moisture on the Hardening Processes in Alfalfa.—H. M. TYSDAL, *U. S. Dept. of Agriculture.*

The hardening processes in alfalfa varieties under controlled light, temperature, and moisture conditions were studied. The extent of hardening was measured by the response to artificial freezing.

A short day (7 hours) greatly increased cold resistance of some varieties but not of others. At very low (0°C) or very high (20°C) temperatures the hardening influence of the short day was not apparent. Shortening the day much below 7 hours made the plants more susceptible to cold. Length of day exerted a greater influence than light intensity. Plants hardened under white light gave higher survival than those under blue or red light.

Plants exposed to constant temperatures increased in hardiness with each progressively lower temperature from 20° to 0°C. The greatest amount of hardening was obtained with plants subjected to alternating temperatures of just above 0° for 16 hours and at 20°C for 8 hours, having light during the warm period. The least hardy plants were those kept in the dark during the warm period and in the light during the cold period.

Lowering the soil moisture content to the wilting point did not greatly harden alfalfa plants, the increase in hardiness of the low moisture group being overshadowed by more rapid lowering of the temperature in the dry soil during freezing. When plants were severely wilted they could withstand given low temperatures much better than plants normally watered.

These studies indicate that light and temperature greatly influence the hardening process and that through their control greater varietal differentiation in cold resistance can be obtained. Environmental field conditions as regards light and temperature in autumn closely parallel controlled conditions conducive to optimum hardening.

5. Artificial Refrigeration as a Means of Studying Winterhardiness.
R. B. Harvey, *University of Minnesota.*

Fifteen years' experience with the artificial winter test has shown that it is the most reliable method of estimating the rate of hardening and the hardening capacity, as well as the rate of losing hardiness. A discussion is given of the time required to acquire and to lose hardiness and of the threshold value of temperature for inducing hardiness. Similarities between the hardening process and encystment of the cells of lower plants are discussed.

SYMPOSIUM ON "SOYBEANS"

Leader: W. J. Morse, *U. S. Dept. of Agriculture.*

1. **Genetics of the Soybean.** C. M. Woodworth, *University of Illinois.*
2. **The Soybean Disease Situation.** S. G. Lehman, *North Carolina State College.*
3. **Soybean-corn Mixtures.** H. D. Hughes, *Iowa State College.*
4. **Effect of Latitude on Growth and Composition of the Soybean.** J. L. Cartter, *U. S. Dept. of Agriculture.*
5. **Commercial Utilization of Soybeans and Soybean Products.** W. L. Burlison, *University of Illinois.*
6. **Utilization of Soybeans and Soybean Products in Oriental Countries.** W. J. Morse, *U. S. Dept. of Agriculture.*

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1. Genetics of the Soybean.—C. M. Woodworth, *University of Illinois.*

The behavior in inheritance of a score or more genes has been worked out in the soybean. Most of these are independent. Three linkage groups are established.

Numerous crosses have been made at the University of Illinois for the purpose of studying the inheritance of characters having to do with the physiology and performance of the plant. Among these may be mentioned the following: (1) softness versus hardness of seed coat; (2) pod-bearing habit; (3) hybrid vigor; and (4) seed yield.

Softness versus hardness of seed coat.—The F_1 was intermediate. The F_2's were variable, extending through range of parents, even showing transgressive segregation. There was a relation to seed color. Nearly all black segregates were hard.

Pod-bearing habit.—Indeterminant was dominant to determinant. In F_2, ratio of 3 to 1 was obtained. Indeterminant taller, with more nodes, than determinant.

Hybrid vigor.—Quite evident in many crosses between varieties. Certain varieties when crossed differ greatly in amount of hybrid vigor shown.

Seed yield.—An analysis of seed yield is being attempted. The varieties were compared on a plant basis as to (1) number of nodes,

(2) number of pods per node, (3) number of seeds per pod, (4) percentage abortive seed, and (5) size of seed. Many varieties were significantly different in these components. Genetic correlations indicated little relationship among the component characters.

2. The Soybean Disease Situation.—S. G. LEHMAN, *North Carolina State College.*

The soybean is often looked upon as a crop which is practically free from disease injury. While the losses from disease may be relatively less than for certain other crops which are more widely and more intensively cultivated, there are, nevertheless, a number of fungous and bacterial diseases of the soybean which cause losses of considerable consequence.

Some studies of the better-known diseases have been made, but much careful work yet remains to be done. Further detailed study should be given to such diseases as bacterial pustule, bacterial blight, and frog-eye. Wilt, stem rot, and root knot are serious diseases of this crop in some areas. Brown spot, pod blight, and anthracnose are of less common occurrence, but often cause significant losses. Other diseases are known to which little or no study has as yet been given.

Our knowledge of effective control measures should be increased, and there is need for the development of varieties or selections possessing inherent high resistance to the more troublesome of the above-mentioned diseases. The possession of resistant or immune strains of desirable varieties would not only reduce losses, but also greatly facilitate rotational practices in the South in particular.

3. Soybean-corn Mixtures.—H. D. HUGHES, *Iowa State College.*

Agronomic experiments dealing with the practice of growing corn and soybeans in association were begun at the Iowa Experiment Station in 1915. During the years 1919 to 1925, inclusive, yield determinations were secured on 2,090 experimental plantings,with rates and methods of growing, season and soil conditions, variety comparisons, and time of planting.

With unusually favorable conditions, corn with beans produced 91.8% of the grain yield of corn alone; under less favorable conditions 81.7 and 82.1% of normal. As an average for all conditions and rates of planting the yield of soybean seed was 51.8% of the reduction in yield of corn grain; under the most favorable growing conditions the proportion of beans to corn was lower and under unfavorable conditions higher.

Averaging nine different combinations of rates and methods of planting, 2.75 stalks of corn competing with 3.87 bean plants per 42 inches of row produced 85.9% of the check yield, the corn loss of 425 pounds being replaced by 248 pounds of bean seed. When the beans were drilled the yield of beans more nearly approached the amount by which the corn yield was reduced than when both the corn and beans were hill planted. When cut as forage the average for all methods and rates was 105.7% of the yield of corn alone; with both crops hill-planted, 101.5%; corn hill-planted and beans drilled, 109.7%; and with both crops drilled, 108.2%.

4. Effect of Latitude on Growth and Composition of the Soybean.— J. L. CARTTER, *U. S. Dept. of Agriculture.*

With the rapid growth of the soybean industry in the United States has come the need of better varieties in each region where soybeans are grown. The Department of Agriculture recently introduced several thousand soybean varieties and selections from the Orient.

The duty of the agronomist is to select the most promising of these introductions for each soybean-growing region, and to test them further for yield, composition, and other factors of desirability for each region.

A soybean variety will vary in height, general appearance, date of maturity, and many other factors of growth when planted in different latitudes. Work has been undertaken to study this response of soybean varieties to latitude. By being able to predict how a variety will react to change in latitude, the agronomist may distribute new selections more rapidly to the region where they will be of value.

Three varieties differing in their date of maturity have been grown cooperatively at experiment stations ranging in latitude from Florida to Canada. Data are presented showing the effect of change in latitude on the growth and on the oil and protein content of these varieties. The seasonal change in number of hours of daylight in different latitudes is charted and the relation of the daylight duration to date of blooming and date of ripening of soybeans is brought out. The effect of time of planting on the date of blooming is also discussed.

5. Commercial Utilization of Soybeans and Soybean Products.— W. L. BURLISON, *University of Illinois.*

It is doubtful if there is any crop in America being so widely discussed from the standpoint of the farm as well as from the standpoint of utilization of the derived products as is the soybean. Someone has called soybeans "The Romance Crop." There is indeed romance surrounding the soybean, especially during its early history in the Old World, as shown by Doctor Morse.

It has passed from the romance stage in the Old World to one of economic considerations, and this is certainly true in America, especially in the corn belt. The spread of soybeans in America has been nothing less than phenomenal, particularly during the last decade. The increase in acreage for 1931 over 1930 in the United States has been about 22%.

Interest is growing in the utilization of soybeans on the farm for feeding purposes. At the same time, we are finding new ways in which to utilize the crop commercially, to great advantage. From practically every corner of the United States queries are arising as to the future possibilities of the soybean. Few if any crops have as many products as the soybean. There are approximately 100 products now being manufactured in this country from the soybean. Many of them have not gone beyond the experimental stage, while others are being placed on the market in large quantities.

From the standpoint of industry, the utilization of soybean oil for edible purposes is becoming of outstanding significance. Certain

companies report that they have no difficulty whatever in disposing of the oil for human consumption. The outlet in this direction is indeed very wide, and we may expect a great development in the next few years.

Next to utilization of soybean oil for human consumption is the use of soybean oil in paint. The amount used for this purpose will be small as compared to that used for human food, but at any rate it is a problem worth thorough consideration. Investigations on the use of soybean oil in paint are under way in certain great industrial establishments and at some experiment stations. With present price levels, revived interest of the oil for soft soap is not without significance.

The feeding of soybean oil will be one of the important outlets for a main product of the soybean. Experiment stations are recommending a wider use of soybean oil meal for feeding purposes.

Just what science will have to say about the soybean tomorrow nobody knows. It is a great crop and deserves to be watched by everone interested in the development of agriculture in the Middle West.

6. Utilization of Soybeans and Soybean Products in Oriental Countries.—W. J. MORSE, *U. S. Dept. of Agriculture.*

In Oriental countries the soybean is grown primarily for the seed which is used largely for human food and in the manufacture of oil and oil cake. Since ancient times the people of China, Japan, Korea, Indo China, and the Dutch East Indies have utilized the soybean in the preparation of numerous fresh, fermented, and dried food products which form an indispensable part of their diet. These food preparations supply to a very considerable extent the protein that in the diet of Western people is furnished largely by meats and milk products.

Manchuria, the largest soybean-producing country in the world, had a production of more than 5,000,000 tons of which more than 400,000 tons were used for food, 253,000 tons for feed, and 225,000 tons for seed. The remainder, more than 4,000,000 tons, was used in the production of oil and oil meal and for export.

Japan in 1929 used over 39,000,000 bushels of soybeans of which only 13,000,000 bushels were grown in Japan proper, the difference being imported from Manchuria and Korea. The following shows the various ways in which this large amount of beans was utilized by the Japanese people: Miso, 22.7%; soy sauce, 22.7%; soybean oil and oil cake, 21.5%; bean curd, 15.4%; confections, 6.1%; forage, 6.2%; green vegetable beans, 0.8%; green manure, 2.5%; seed, 1.6%; and miscellaneous, 0.5%.

GENERAL CROPS PROGRAM

CHAIRMAN: R. I. THROCKMORTON, *Kansas State Agricultural College.*

Environmental Relations and Grub Injury of Bluegrass.—L. F. GRABER, *University of Wisconsin.*

That the environment has a most profound influence on the degree of injury sustained by bluegrass (*Poa pratensis* L.) from infestations of white grubs (*Phyllophaga* spp.) has been made manifest by field observations and controlled experiments at the Wisconsin Experiment Station. The severe outbreaks which occurred in 1927 and 1928 and which recurred in 1929 and 1930 have caused heavy losses in the destruction of thousands of acres of pasture sods in southern Wisconsin. Most species of the white grub have, normally, a life cycle of 3 years of which about two-thirds is spent in the larval stage so that during all or a part of each year these insects feed on grass roots and rhizomes.

In general, under field conditions, wherever the root and rhizome development of bluegrass (the dominant species) was retarded by deficient fertility or deficient organic food reserves, due to close premature grazing, or by thin and dry soils, due to hillside outcroppings of limestone or flint, the injury was made most evident by a rapid secondary succession of ragweeds (*Ambrosia* sp.), mullein (*Verbascum* sp.), and other undesirable plants.

In the field, not only were the grubs more numerous with an unfavorable environment, but with equal numbers of grubs in controlled cultures of bluegrass the injury was most severe when one or several factors retarded the quantitative development of subterranean growth and its regenerative activity.

Studies of the Hardiness of Plants.—S. T. DEXTER, *University of Wisconsin.*

A method for the study of hardiness of plants is presented, based upon the principle that mineral matter will readily diffuse from tissues injured by freezing, whereas it is retained by those tissues sufficiently hardy to escape injury. By measuring the electrical conductivity of water into which this exosmosis has taken place, the degree of injury may be determined.

Charts and figures are shown which demonstrate the rate and ultimate hardening of several varieties of alfalfa throughout the autumns of 1929 and 1930. Further application of the method to varieties of red clover from different parts of the world and to field-grown winter grains gave satisfactory results in detecting the recognized varietal differences in cold resistance. In each case, varieties of known hardiness gave much less exosmosis than tenderer varieties.

Individual roots of several varieties of alfalfa were studied by another method based upon the principle that the electrical conductivity of the root itself is increased by freezing injury. Marked differences in the hardiness of individuals within a variety could be shown, as well as the gross varietal differences. It was shown that in the Grimm alfalfa root hardening begins at the crown, and that the

uppermost parts of the root in November are distinctly less injured by artificial freezing than those parts more deeply buried. With a very tender strain, such as Hairy Peruvian, there was but little difference in hardiness found in different parts of the same root.

Root Development in Hardy and Non-hardy Winter Wheat Varieties. WALLACE W. WORZELLA, *Purdue University.*

The root systems of eight varieties of hardy and non-hardy winter wheats were studied at various intervals during two successive seasons, 1929–30 and 1930–31. The purpose was (1) to study differences, if any, in the nature and development of the roots, and (2) to ascertain the relation between the differences that may be found and resistance to winterkilling. The 1929–30 season was cool and wet and the roots grew slower and did not penetrate as deep as did the roots in in 1930–31 when it was warmer and drier. There appeared to be no significant differences as to the average length and depth of seminal roots, although the non-hardy varieties showed greater average spread from the base of the plant than the hardy varieties.

Most of the seminal roots of the non-hardy varieties developed almost horizontally in the early stages of growth with most of the spread remaining at comparatively shallow depths then turning downward, whereas in the hardy varieties most of the seminal roots ran obliquely outward or straight downward with very little spread near the surface.

Adventitious roots showed little development in the fall, but grew rapidly in the spring. Roots of mature wheat plants were found to penetrate to a depth of 70 inches.

The Relation of Weather to Root Reserves and Time of Cutting in Alfalfa.—C. J. WILLARD, *Ohio State University.*

It is a matter of common observation that alfalfa is usually more injured by frequent cutting east of the Mississippi than west of the Missouri. In the dry year of 1930, alfalfa at Columbus, Ohio, yielded rather less than half a normal crop of hay during the season, but root reserves increased steadily throughout the year. The increase in weight of roots during the year amounted to from 1/4 to 2/5 of the yield of hay produced. Alfalfa went into the winter of 1930–31 with about 1,000 pounds per acre more root reserves than normal. Cutting four times in 1930 did not weaken the stand or prevent root storage as in normal years. The coefficient of correlation of average daily root storage with average daily rainfall was $-.44 \pm .07$ for 61 records during 7 years.

In a dry season or climate alfalfa uses a smaller proportion of the materials produced by photosynthesis in top growth and a larger proportion in root growth than in a wet season or climate. Consequently, the western farmer, in a dry climate, can cut his alfalfa rather carelessly, and the climate will prevent undue exhaustion of the roots, as it did in Ohio in 1930.

The eastern farmer, on the other hand, is in a climate which normally favors the exhaustion of most of the reserve material from

the roots into the tops. If he does not take special precautions in cutting, his alfalfa may be weakened and killed by cutting at intervals which would not be injurious further west.

A Comparison of Chamber and Field Germination Tests in Soybeans.—G. H. CUTLER, *Purdue University.*

Current among soybean growers is an opinion that soybean seed germinates better in the field than the chamber test would seem to warrant.

Data were gathered covering a period of 4 years on different varieties of soybeans, comprising several hundred tests. Studies with the Manchu variety were more extensive than with the others.

Three hundred twenty chamber tests and 480 field tests made during the seasons of 1928, 1929, 1930, and 1931 on corresponding lots of seed representing 41 pure-line strains of Manchu showed a difference of $5.04 \pm .57\%$ in favor of the chamber tests.

Data obtained during the same period with the Dunfield variety supported these results. On the other hand, data obtained from 300 chamber and 150 field tests covering a period of 2 years from random samples taken from the Wilson 5 showed no measurable difference.

Several factors seem to influence the results obtained. Among these the following have been studied: Season and soil, condition of seed, and variety and strain of soybeans.

Cytological Aberrations in Relation to Wheat Improvement.—LEROY POWERS, *University of Minnesota.*

Marquillo wheat, grown commercially to some extent in Minnesota, is the result of a cross between Marquis (vulgare) and Iumillo (durum). Marquillo proved to be somewhat more variable in agronomic characters than Marquis, but not any more variable than some other commercial varieties, such as Supreme. Cytological studies of microsporogenesis of Marquillo were made. It was decided to include Marquis as a check and Minn. 2303 because it represents a further cross of a selection from a Kanred x Marquis cross.

In these studies not less than 15,000 microspores and 2,800 microsporocytes of each variety were examined, involving approximately 30 plants of each variety. Marquillo was found to exhibit a higher percentage of chromosomal aberrations than either Marquis or Minn. 2303, whereas the latter two varieties were approximately equal in this respect.

The progeny of the plants of Marquillo studied cytologically were grown and statistical measurements of a few simple plant characters were taken. The coefficients of variability of these characters were found to be associated with the cytological aberrations studied in the parental plants.

The results with Minn. 2303 show that germinally stable varieties may be obtained from interspecific crosses, involving the emmer and vulgare groups.

Correlation Studies with Strains of Flax with Particular Reference to the Quantity and Quality of the Oil.—I. J. JOHNSON, *University of Minnesota.*

Forty-six varieties and crosses of flax were grown in 1929 and 1930 at University Farm, St. Paul, Minnesota. During each of the 2 years the percentage of oil, dry weight of 1,000 seeds, date of maturity, number of days from full bloom to maturity and, in 1930, the iodine number were studied. During both years the percentage of oil and, in 1930, the iodine number were correlated with each of the other characters by means of simple and partial correlation. Significant positive correlations were obtained between the percentage of oil and weight of 1,000 seeds, date ripe, and number of days from full bloom to ripe. A significant simple correlation between iodine number and weight of 1,000 seeds was obtained. Other simple correlations with iodine number were all negative but not statistically significant.

A further study of these relationships made in partial correlations gave a high positive correlation between percentage of oil and weight of 1,000 seeds and a significant negative correlation between iodine number and weight of 1,000 seeds with other variables constant.

Inter-annual correlations made between each of the characters studied indicated that they were relatively constant in their inheritance.

An Indication of the Relative Susceptibility of Dent and Flint Corn to Injury by Grasshoppers.—A. N. HUME, *South Dakota State College.*

Outbreaks of grasshoppers have been known to occur in several sections of the Middle West in the past season. These outbreaks have been described and technical means for combating such ravages by insects have been proposed by entomologists.

Corn growers and others, including agronomists, have had opportunity to note important variations in the susceptibility of different crops to grasshopper injury. An outstanding example of this, so evident to general observers as to require no proof, was the fact that sorghum, including saccharine and non-saccharine varieties, remained uninjured in areas where dent corn and many other crops were utterly devastated.

Evidence is presented to show that the injury to dent corn by grasshoppers was greater than to flint corn. The foliage of dent corn was devoured, whereas the flint corn, although somewhat injured by the insects, was able to function.

GENERAL SOILS PROGRAM

CHAIRMAN: W. W. BURR, *University of Nebraska.*

The Conservation of Soil Moisture and the Theory of Vapor Movement.—W. W. BURR, J. C. RUSSEL, AND H. E. WEAKLY, *University of Nebraska.*

In the conservation of soil moisture, the control of vaporization is considered to be equally important with the control of weeds. Capillarity deserves little attention. Water evaporates within the soil and escapes as a vapor. An understanding of vaporization phenomena is important.

The magnitude of evaporation can be expressed by the formula

$$\frac{E}{TA} = \frac{K\,(M_w - M_a)}{l} \cdot \frac{B}{f\,B_1} \quad \frac{E}{TA} = \left(\frac{K\,(M_w - M_a)}{l} \cdot \frac{B}{B_1}, \right)$$

where $\frac{E}{TA}$ is water evaporated expressed in mass units per unit of time, T, and transpirational cross section A, fB_1 is a function of barometric pressure in terms of a standard pressure B, K is constant of proportionality, and $\frac{(M_w - M_a)}{l}$ is an expression of saturation deficit gradient.

The latter is derived from the familiar Dalton expression of vapor pressure deficit $(p_w - p_a)$ by conversion of pressure units p to mass units M and taking into consideration the depth l of the air column through which the vapor pressure deficit operates.

Evaporation of water from soil would seem to be controlled when M_w in the above expression is low, M_a is high, and l is large. M_w is low when the temperature of the soil is low, M_a is high when there is a stagnant, highly saturated blanket of air over the soil, and l is large when this blanket of air is deep. Such conditions naturally obtain in cool, damp, calm weather. Shade and mulches, either of straw or earth, would seem to be the most effective ways under man's control of keeping the soil cool. Wind breaks of any sort, like stubble, stalks, growing crops, or a roughened soil surface, should serve to stagnate and raise the humidity of the air immediately over the soil.

Evaporation within the soil occurs at a very slow rate at depths of several inches below the surface, except when the soil is unreasonably porous, and the main objective in vaporization control is the conservation of the small rains that are largely retained in the top few inches.

Cloddy or roughened surfaces that magnify the depth of rainfall by concentrating it in smaller areas lead to penetration beyond the zone of rapid evaporation.

In light of vaporization phenomena, a consideration of the shading and wind break effects of growing crops, the presence in the surface few inches of roots to compete with vaporization for the small rains, and the difference in the character of soils and summer precipitation explain why summer tillage is not equally effective in all sections and why the conservation of moisture by summer tillage varies so from season to season.

Muck Soil Reaction in Relation to Crop Production and the Advisability of Its Use as a Basis of Muck Soil Classification.—PAUL M. HARMER, *Michigan State College.*

Of the several characteristics by which organic soils may be classified, such as soil reaction or lime content, state of decomposition, depth of muck, and nature of the underlying material, the soil reaction is by far the most important in so far as the agricultural productivity of these soils is concerned. Depth and the nature of the underlying material are also important from the standpoints of drainage and crop adaptation, while the state of decomposition is generally of such a temporary nature as to render it of little value in a classification unless the very immediate productivity of the soil is being considered.

The muck soils of Michigan may be classified in three main groups as regards their soil reaction, as follows:

(1) Low-lime (very strongly acid) muck, (2) high-lime (not acid to strongly acid) muck, and (3) alkali (alkaline) muck. These three groups differ in their native vegetation; in their response to different fertilizers, lime, and other chemicals; and in their adaptation to different crops and even to different varieties of certain crops.

The very strongly acid mucks may be characterized by (1) a native vegetation which may include leather leaf (*Cassandra*), blueberry, cranberry, dwarf tamarack, black spruce, a barren area, and sometimes marsh grass or poplar; (2) by a response to heavy applications of lime; (3) by a response to complete fertilization and sometimes to an application of copper sulfate; and (4) by a tendency toward premature maturity which is overcome by proper treatment.

The high-lime (not acid to strongly acid) mucks may be characterized by (1) a native vegetation of black ash, elm, maple, white cedar, large tamarack, and sometimes marsh grass; (2) by a decrease in crop yield in response to liming; (3) by a response to potash, and generally to phosphate also, for all crops and to nitrogen for a few crops; and (4) by a good yield of high-quality produce where properly drained and fertilized.

The "alkali" mucks may be characterized by (1) a native vegetation similar to that of the high-lime group, or a scant vegetation, if especially strong in "alkali"; (2) by a response to applications of sulfur and sometimes also to improvement in drainage; (3) by a response to phosphate and potash for all crops and to nitrogen for some; and (4) by a tendency toward delayed maturity, slow growth, and poor quality of many crops, a condition which is overcome by the application of sulfur.

A determination of the classification of a given muck soil should include not only the determination of the reaction of the surface layer, but also that of the underlying muck to a depth of at least 2 and preferably 3 feet.

Effects of Various Kinds and Amounts of Lime on the Degree of Saturation of Some Southern Iowa Soils with Bases.—R. H. WALKER AND P. E. BROWN, *Iowa State College.*

In greenhouse tests the degree of saturation of Grundy silt loam with bases was increased from 60.13% to 81.30% by the application

of 3 tons of pure calcium carbonate and to 95.52% by the same material at the rate of 6 tons per acre. Similar amounts of pure calcium carbonate effected larger changes in the degree of saturation of Shelby loam and Tama silt loam. Quarry-run limestone induced considerably smaller changes than did the pure calcium carbonate.

Hydrated lime and 100-mesh limestone had about the same effects, while the coarser materials were considerably less effective in increasing the degree of saturation. Pure magnesium carbonate was slightly more effective than pure calcium carbonate, but calcium limestone was more effective than dolomitic limestone.

In field tests the degree of saturation of Grundy silt loam was increased in 6 months from 65.75% in the untreated soil to 70.86% by the application of 3 tons and to 79.41% by 6 tons of quarry-run limestone. Hydrated lime and 100-mesh limestone were considerably more effective than twice as much quarry-run limestone in increasing the degree of saturation of this soil with bases.

Determining the Effect of the Degree of Slope on Runoff and Soil Erosion.—F. L. Duley and O. E. Hays, *Kansas State Agricultural College.*

Determinations of runoff and erosion were made on a tank of soil 10 feet long, 2 feet wide, and 2 feet deep, placed at different degrees of slope varying from 0 to 20%, and also on field plats 25 feet long and 3 feet wide placed at different angles on a hillside so that the slope could be varied from 0 to 13%. Water equivalent to a definite amount of rainfall per hour was applied artificially.

The results show that there is a very rapid increase in the amount of runoff when the slope is increased from 0 to about 3%. With a still further increase in slope the increase is much less rapid and the runoff does not increase in proportion to the slope. As the soil becomes more saturated or as the rate of rainfall increases, the more rapid is the rate of increase of runoff with the first increase in slope up to about 3%. The amount of soil eroded shows a very slow increase until the slope is about 4%. Then with steeper slopes there is a very rapid increase in the amount of soil removed. That is, with the steeper slopes a given amount of water removes a much greater quantity of soil than from more gentle slopes.

Further Studies on Soil Respiration.—F. B. Smith and P. E. Brown, *Iowa State College.*

A comparison of soil respiration by the Lundegardh method and the Humfeld titrametric method was made. There was apparently no relation between the rates of respiration by the two methods.

The rate of respiration during several successive periods at different times by the Lundegardh method, the concentration of carbon dioxide at different depths, its accumulation under the respiration bell, and the evolution of carbon dioxide from soil taken from different depths were determined. It was concluded that soil respiration is not a simple diffusion of carbon dioxide through the soil and its evolution at the surface.

The Effect of Fertilizer Use on Total Crop Production.—H. R. SMALLEY, *National Fertilizer Association.*

An estimate based on crop values for the 3 years 1926–28 and fertilizer consumption in 1928 and excluding the western group of 11 states shows that 11.5% of the value of all crops may be attributed to the use of fertilizer. That part of the total crop value produced by fertilizer in New England was 16.2%; in the Middle Atlantic States, 15.5%; in the Southeastern States, 46.4%; in the South Central States, 29.3%; in the Southwestern States, 5.6%; in the East North Central States, 8.9%; in the West North Central States, 0.9%; and in the Great Plains States, 0.1%.

For the important crops the figures were as follows: Corn, 6%; cotton, 28.9%; tobacco, 42.2%; potatoes, 26.6%; vegetables and fruits, 24.7%; wheat, 8%; oats, 3.5%; hay, 1.0%; and miscellaneous crops, 1.6%.

These estimates are based on a survey made in 1928 on 48,000 farms in 35 states and on the crop estimate of the U. S. Dept. of Agriculture.

The Neubauer and Winogradsky (Azotobacter) Methods as Compared With a Chemical Method for the Determination of Phosphate Deficiency in Western Soils.—H. W. DAHLBERG AND ROBERT J. BROWN, *The Great Western Sugar Co., Denver, Colo.*

After 300 samples of soils from Colorado, Wyoming, Montana, and Nebraska had been tested for phosphate deficiency by the Neubauer method and some 10,000 samples by the Winogradsky method, a new and rapid chemical method was worked out for soils of this type. In order to standardize the latter method, 101 different soils were carefully checked by all three methods. The agreement between the three methods was as follows:

73 out of 101 agree by all three methods.
83 out of 101 agree by Neubauer and Winogradsky methods.
82 out of 101 agree by Neubauer and chemical methods.
75 out of 101 agree by Winogradsky and chemical methods.

The percentage of agreement is still higher on the most deficient soils, classified as group C soils. Since the laboratory results have in some cases been confirmed by field trials, the authors believe that in general any one of the three methods may safely be substituted for the latter.

The chemical method is a somewhat radical modification of the Illinois method in which the soil is extracted with 0.25 N, 5.0 pH sodium acetate buffer solution, rather than with the acid molybdate reagent. The method is described in detail. As yet it is recommended only for soils of 7.0 pH and above, and for soils containing appreciable quantities of acid-soluble P_2O_5.

The Correlation of Certain Lesions in Animals With Certain Soil Types.—J. G. HUTTON, *South Dakota State College.*

For many years it has been observed that certain lesions in animals occur in certain localities and that stockmen and farmers believe that these lesions are definitely related to certain soil types.

The lesions consist, so far as may be observed externally, in the loss of hair (alopecia) from certain parts of the body, particularly mane and tail in horses, although other parts of the body may become bare, and in the case of hogs the body may become almost hairless. Chickens may lose their feathers and the eggs of chickens produced in the area may not hatch or may produce chicks with abnormalities particularly as to feathers. Animals often lose their hoofs and develop stiffness of joints and frequently die.

A survey of a typical region in 1922 found that the lesions mentioned above are apparently related to the grain and forage produced upon certain undetermined small areas within the larger area of soils weathered from Cretaceous shales.

The Nature of Phosphate Fixation in Soils.—A. FLOYD HECK AND E. TRUOG, *University of Wisconsin.*

When soluble phosphates are applied to soils, a fixation takes place which results in the formation of phosphates which have a low solubility in water. If there is an abundance of readily available lime present, all or at least a large portion of the phosphate will be fixed as tricalcium phosphate which has a relatively high availability to plants. On the other hand, if the soil is sufficiently acid so that readily available lime is lacking, the phosphate will usually be fixed largely as basic iron and aluminum phosphates.

Soils of high fixing power, that is, those containing an abundance of readily available lime or certain hydrated oxides of iron and aluminum, fix the soluble phosphates very quickly and, as a result, the downward movement of soluble phosphates applied as fertilizer may be restricted largely to the surface inch or even one-half inch. Soils vary greatly in their rate and character of phosphate fixation. This is a very important factor which should always be considered in phosphate fertilization.

By means of chemical methods, it is now possible to distinguish, with a fair degree of satisfaction, between the readily and difficultly available phosphorus as well as between soils of low and high fixing power.

Some Economic Factors in Delayed Application of Fertilizer.—HARRY W. WARNER, *The Barrett Company.*

On many soils requiring relatively large amounts of fertilizer it is more economical to make delayed application of part of the added plant food than to apply all at one time, either before or at planting. This fact furnishes the economic basis for the practice of side-dressing and top-dressing, as now widely followed in heavy fertilizer-using sections.

Some important factors that influence the economy of delayed application of fertilizer, are: (1) moisture-retaining capacity of the soil; (2) moisture supply,—amount and distribution; (3) plant food supply, exclusive of fertilizer applied; (4) plant food requirements of crop grown; (5) rate of application possible without injury to crop.

In addition to the usual effects of fertilizer on crop yield, quality, and maturity, delayed applications may produce certain additional benefits or advantages: (1) greater degree of control over the growth and development of the crop; (2) more efficient utilization of the readily leachable plant foods; (3) less danger of injury from heavy applications; (4) some saving in cost of plant food.

The ideal system of fertilization, theoretically, would be to make frequent delayed applications, each of small amounts. With the exceptions of a few highly specialized crops, this system is impractical from the standpoint of efficient farm management. Such a system, also, is not consistent with the recognized behavior of mineral plant food after being applied to the soil.

Experimental results and practical experience are responsible for the present fertilizer practice in this country, which may be briefly stated: Apply all the minerals and about one-half the nitrogen under the crop; apply the remainder of the nitrogen as side- or top-dressing after the crop begins to feed heavily on this element.

A change from the present established practice to one in which part of the mineral plant food is applied as side- or top-dressing, will no doubt be officially recommended when these questions are answered affirmatively: (1) Are the minerals more completely utilized when applied in split application? (2) Can the farmer further profitably increase the rate of application by adopting this practice? (3) Are there adequate data to show that a given amount of mineral plant food supplied in split applications will return a greater profit than the same total amount applied under the crop? Experiments now being made in some States are planned to secure answers to the questions involved.

The further development of the practice of making delayed application of fertilizer will benefit the fertilizer industry (1) because of the possibilities of increased tonnage and (2) because it will lengthen the seasons of sales and delivery. The several advantages to the farmer of delayed fertilizer application have already been outlined.

The problem of delayed application of fertilizer—the when phase—is a field for investigation that promises increased profits for the farmer and a larger market for commercial plant food.

A BIBLIOGRAPHY ON CALCIUM CYANAMID

A bibliography in mimeographed form has recently been issued by the American Cyanamid Company on important articles and abstracts dealing with calcium cyanamid. The bibliography is divided into two parts, *viz.*, one dealing with articles in the English language and listing 210 titles, and one dealing with articles in languages other than English and listing 93 titles. A copy of the bibliography may be obtained upon request by addressing the American Cyanamid Company, 535 Fifth Avenue, New York City.

JOINT MEETING WITH SECTION O

A joint meeting of the Society with Section O of the American Association for the Advancement of Science and the geneticists interested in agriculture has been arranged for Monday and Tuesday, December 28 and 29, at Tulane University in New Orleans.

On Monday afternoon, the program will be given by the geneticists. On Tuesday, the program will center largely around the use of fertilizers on southern soils. Fourteen papers are on the program and many of them deal with special phases of fertilizer studies on the soils in some of the southern states.

On Tuesday evening, the annual dinner will be held at which time the address of the retiring vice-president and chairman of Section O, Dean W. C. Coffey of Minnesota, will be presented. His subject will be, "The Interrelationship of the Biological and Social Sciences in Agricultural Education."

On Monday there will also be a meeting which may be of interest to many in agronomy, when a program will be presented around the subject of flood plain biology and agriculture.

MEMBERSHIP DUES IN THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

Members of the International Society of Soil Science are urgently requested to send payments for their 1932 dues at once to Dr. A. G. McCall, Room 125 East Wing, U. S. Dept. of Agriculture, Washington, D. C. Early in 1932 all mailing lists for publications will be closed and only those members whose payments for dues have reached the office of the General Secretary abroad by that time will be enabled to receive without charge the Journal and Soil Research as well as Volume A of the Proceedings of the Sixth Commission meeting at Groningen in 1932. Members cannot afford to miss the opportunity to secure the Transactions of the Second Congress held in Russia at the special price accorded to them, hence remittance should be made promptly.

NEWS ITEMS

Arthur H. Post, Associate Agronomist at Montana State College, is taking a year's sabbatical leave effective September 1, 1931. He is doing work toward the doctorate in the Soils Department at the University of Wisconsin.

Harold Tower, Office of Forage Plants, U. S. Dept. of Agriculture, Moccasin, Montana, has been granted nine months temporary leave without pay, effective September 10. He is doing graduate work at the Kansas State Agricultural College.

Sam Sloan, formerly county agent in Fall River County, South Dakota, was appointed Extension Agronomist at Montana State College, effective August 1.

Waldo Kidder resigned as Extension Agronomist at Montana State College on June 1 to accept a position with the American Agricultural Chemical Company.

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